MODERN LIGHTNING CONDUCTORS

KILLINGWORTH HEDGES,

M. Inst. C. E.

Modern Lightning Conductors:

AN ILLUSTRATED SUPPLEMENT TO THE

REPORT OF THE LIGHTNING RESEARCH COMMITTEE

OF 1905,

Also the PHŒNIX FIRE OFFICE 1910 RULES,

WITH NOTES AS TO THE

METHODS OF PROTECTION AND SPECIFICATIONS,

BY

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PREFACE.

THE large amount of information furnished by the Observers' Reports of the Lightning Research Committee, and accumulated during the past four years, have of necessity been curtailed in their recently published Report. I have, therefore, selected and illustrated some of the most typical cases, and given details which may be found useful to architects and those who wish to go deeper into the question of protecting buildings from lightning.

The suggestions and rules of the Lightning Research Committee open up a new field of enquiry, and it is to be hoped that the theories which have so long been put forward by Sir Oliver Lodge and other scientists will now come into existing practice. With the view of facilitating this, the methods which I have found most suitable are explained, and illustrations are given of some of the necessary accessories, also a short description of the arrangements in use on the Continent.

As a rule the path taken by lightning when striking a building is intelligible, but there are many instances where it has shown such curious freaks that it was thought that a summary of a few of these, under the heading of "Vagaries," might be included, also the account of the "Effects of Lightning on a Rod," furnished by Mr. William Maine, South Carolina, 1760.

The Lightning Rod Conference of 1882 undoubtedly did good work, as it crystallised the best practice of the day, calling attention to the methods of dealing with conductors in the interior of buildings, and laid down most useful rules; but it was left to Sir Oliver Lodge to be the first to again take up the question, and to urge the necessity for modified methods. His first appeal passed almost unnoticed by the general body of architects and engineers, and very few thought about the matter, being satisfied generally with the regulations drawn up by the Conference. It is interesting to note that the English Committee of 1901 are not alone in attaching great importance to this subject. Their general conclusions agree closely with the independent reports of the various Continental authorities and committees, whose opinions are quoted, therefore the committee's suggestions are put forward as not only the results of their own investigations, but also the practical opinions of all those who have been similarly engaged abroad.

My thanks are due to the Lightning Research Committee* for the permission to reproduce their Report, including the Analysis of Selected Cases of Protected Buildings damaged by Lightning—Appendix A. I must also gratefully acknowledge the help I have received from Sir Oliver Lodge, whose introduction to the L.R.C. Report I now re-publish by kind permission, as it sets out so clearly the theory of lightning, and the way one can, to a great extent, protect a building by suitable conductors, and thus dissipate its energy.

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10, *Cranley Place,*
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July, 1905.

* Also to the Architectural Review for the frontispiece.

INTRODUCTION TO THE LIGHTNING RESEARCH COMMITTEE'S REPORT, 1905.

By SIR OLIVER LODGE, F.R.S.

SINCE the report, many years ago, of the Lightning Rod Conference, knowledge of the subject has considerably increased, and the effect of self-induction, which then was completely ignored, has been taken into account and understood. The main difference between what is recommended to-day and what was considered sufficient then depend on the recognition of the influence of self-induction or electrical inertia. Then electricity was treated as if it had no inertia, and as if all that was necessary was to get it from the clouds to earth as quickly and easily as possible by the shortest path—which may be called the drain-pipe theory. It was supposed that it would always take the easiest path, and that the easiest path would protect all others. Attention was directed to the quantity of electricity which had to be conveyed down, and to nothing else

Now, however, it is perceived that it is not so much quantity of electricity that has to be attended to, as electrical energy; that this electrical energy is stored between clouds and earth in dangerous amount; and that our object should be to dissipate it, not as quickly, but as quietly as possible. A sudden dissipation of energy is always violent. No one in his senses wishes to stop a flywheel

or a railway train suddenly ; sudden or hasty dissipation is not what is wanted. Gun-cotton possesses a store of potential energy locked up in it to a dangerous extent ; if it be dissipated suddenly, as by percussion, a violent explosion results ; but if it be dissipated gradually, as by a flame, the energy is got rid of without much damage, beyond the liability to fire. An armour-plate may be able to stop a cannon-ball quickly, but a heap of sand or loose earth does it more safely, because more gradually.

So it is exactly with the store of energy beneath an electrified cloud, or between one cloud and another. A lightning conductor of perfect conductivity, if struck, would deal with the energy in far too rapid and sudden a manner, and the result would be equivalent to an explosion ; a conductor of moderately high resistance, such as an iron wire, would get rid of it in a slower and therefore much safer and quieter manner, though with too thin a wire there may be a risk of fire.

The rush in any case, however, is likely to be rather violent ; and, like an avalanche, it will not take the easiest path provided for it, as if it were a trickling stream, but will crash through obstacles and make its own path, some portion of it taking paths which would be quite unexpected. Hence no one path can be said to protect others, and the only way to protect a building with absolute completeness is to enclose it wholly in metal. An invisible cage or framework of iron wires, however, descending vertically down its salient features, with the utilisation of any metal in its construction, suffices for all practical purposes, unless the building is a powder magazine.

The effect of *points*, and of rain also, in gradually dissipating a charge, and thereby contributing to safety, has long been understood ; but the feature which has not been known is that there are cases when points are wholly inoperative, viz., when the energy is stored between cloud and cloud, instead of between cloud and earth, and when the initial discharge takes place from

one cloud to another; then the lower cloud is liable suddenly to overflow to earth through a region in which there was no previous preparation, and where any number of points, or a rain shower, or any other form of gentle leak, would have been quite inoperative. Then can a violent discharge occur even to the sharpest point; and a hot column of air, such as rises up a chimney, is even preferred to a conductor. These are the flashes against which points and rain are no protection, and these are probably those which do the most damage to protected buildings. But it must be understood that when a flash does occur through a building, it matters little which kind of flash it is—both can be equally sudden and violent—but if the building is well provided with points, the first or prepared kind is not likely to occur, save in exceptional cases; the dangerous liability is then the sudden or overflow variety of flash.

These, then, are the two points of novelty:

1. The possible occurrence of a totally unprepared-for and sudden flash in previously unstrained air, by reason of overflow from a discharge initiated elsewhere: what is called the B spark, occurring as the secondary result of an A spark.

2. The effect of electrical inertia or momentum, so that the discharge is not a simple leak or flow in one direction, but a violent oscillation and splash or impulsive rush, much more like an explosion, and occurring in all directions at once, without much regard to the path which had been provided for it; no more regard, in fact, than is required to enable the greater part of it to take the good conductors, and to prevent any part of it from being able to enter a perfectly enclosed metallic building.

Even a small lateral fraction of a flash is able, however, to ignite gas if there is a leak, or even to make a leak at a "compo"-pipe where it is crossed by a bell wire, and then ignite it; hence, after a building has been struck, careful watch should be kept for some time against the danger of fire.

The amount of protection to be allotted to any building is no doubt analogous to the question of insurance generally; that is to say, the amount of premium it is desired to pay may be compared with the capital at stake and the risk run; and this is doubtless a matter for individuals and public bodies to consider for themselves. What the Committee can do is to make a study of cases of damage occurring to buildings which on the old lines were supposed to be protected, to tabulate them as below, and to ask for carefully recorded observations; they can also draw up such hints and suggestions as may be of use to architects whose clients desire their buildings to be protected in a more thorough, but not necessarily a more expensive, manner.

These objects, and these attempts at being useful, explain the existence of the present report.

PREFACE TO THE SECOND EDITION.

THE principal reason for issuing a second edition is due to the enterprise of the Phoenix Assurance Company, who having in the past been the first office to issue rules for electric light and power installations, now take the same position with regard to the erection of lightning conductors. The Author and his Colleagues have in these rules followed the recommendations of the Lightning Research Committee's 1905 Report, but have endeavoured to remove any uncertainty as to the Committee's suggestions; it is to be hoped that architects and others who have to specify for the protection of buildings from lightning will insist on the rules being observed, and thus increase the security of buildings fitted with modern lightning conductors. The author acknowledges with thanks the permission of the Phoenix Assurance Company to include their rules.

A chapter has been added on the "Effects of Lightning on Mankind," with notes as to "Where to Seek Safety During a Storm"; also on "Upward Strokes of Lightning," and other interesting phenomena.

K. H.

April, 1910.

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OF

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FIG. 1.

THE BAD ARCHITECT, BY PHILIBERT DE L'ORME, 1560.

Modern Lightning Conductors.

CHAPTER I.

GENERAL CONSIDERATIONS.

THE study of atmospheric electricity dates from very early times; it is doubtful whether the supposition that the art of protection from lightning was known to the Egyptians,* but the Greeks and Romans are reported to have drawn fire from the sky, and Tullus Hostilius is said to have perished in a sacred experiment of this kind; and Cicero, in his ode against Catiline, drew attention to the bad omen to Rome that was caused by the gilded figure of Romulus being destroyed by lightning. The same stroke, mentioned by Virgil, Æneid VIII., burnt the hind legs of the well-known bronze Capitoline Wolf, probably by a side flash. The damage can still be seen by the tourist who visits the Capitoline Museum, where the bronze is now placed. The frontispiece (Fig. 1), selected from Philibert de l'Orme's work, dated 1560, entitled "L'Instruction," shows that architects at that period had to contend with thunderstorms.† It is

* Brugsch suggests that the grooves on Pylon Towers were used for masts designed to protect Egyptian temples.

† Philibert de l'Orme was the architect of the Tuileries and died in 1570.

generally supposed that Divisch, a learned priest, erected the first lightning conductor in Europe at Prendiz, Bohemia, in 1754; the rod was said to have been 130 feet high, and although he was patronized by the Emperor and Empress Frances Stephen and Maria Theresa, it had to be taken down a year later, as it was said to have occasioned a terrible drought. It is not likely that Franklin had heard of Divisch, and although it was due to a communication from Mr. Thomas Hopkinson, an American gentleman, in 1747, that his attention was turned to the matter, he is universally acclaimed as the inventor of the lightning rod which was made known in 1752, and which the European *savants* explained in accordance with scientific theories then current, as a conductor of a supposed "electric fluid" darting from the clouds to earth. Up to the year 1881 there was not even a code of rules in the United Kingdom to guide people in protecting their buildings from the destructive effects of atmospheric electricity. To the efforts of the Royal Meteorological Society we owe the first set of rules, commenced by a conference of learned societies which was formed in 1878, and who brought forward their report, known as that of the Lightning Rod Conference, on December 14th, 1881. Nothing further was done until 1901, when interest in the subject was again revived, first in Germany by the Elektrotechnische Verein of Berlin, who, after much discussion, published on July 21st a set of rules and recommendations for the protection of buildings, and on the 22nd January of the same year the Lightning Research Committee was organized jointly by the Royal Institution of British Architects and the Surveyors' Institution. The following circular was issued:—

"Having regard to the risk of damage by lightning to which our most valuable and historical buildings and monuments are liable, and against which existing systems of protection do not appear to provide sufficient safeguards, the above Committee has been appointed for the purpose of obtaining trustworthy information on future disasters from lightning, with a view to improving, if possible, the means of protection.

"In pursuance of this enquiry the Committee seek the co-operation of competent observers in all parts of Great Britain, in order to obtain accurate details, noted on the spot, of the effect of lightning strokes on buildings, whether fitted with lightning-rods or not, and as full information as possible on the various matters indicated in the Schedule of Questions prepared for the guidance of observers.

"Persons willing to assist the Committee by acting as observers are requested to be good enough to sign and detach the form below, and forward it to 'The Secretary, Lightning Research Committee, R.I.B.A.,

9, Conduit Street, W.,' who will at once supply them with copies of the Schedule above mentioned.

" *To the Secretary, Lightning Research Committee.*

" *The undersigned is willing to act as observer for the District of*

....

in the County of..

" *Name*..

" *Address*...

....

....190............"

and 225 persons enrolled their names as observers, and with others, who acted on the invitation of the Post Office and Institution of Electrical Engineers, have submitted detailed reports of the damage occasioned in 115 cases, 75 of which related to buildings without lightning conductors. *The remaining 40 were provided with what had been considered by those responsible for the buildings as sufficient safeguards in the way of lightning rods.* While taking due account of the lessons to be learnt from the action of the lightning on unprotected buildings which have been injured, the Committee have deemed it unnecessary for the purposes of this Report to go into the details of these cases. A selection, however, has been made from the reports of "protected" cases, and these will be found summarised and put into tabular form in Appendix A, with observations in some instances of the conditions which appear to the Committee to have contributed to the failure of the means of protection provided. The total number of cases reported in the newspapers in Great Britain during this period, 1901–1904, amounted to over five hundred.

The questions that the observers were asked to reply to were as follows:—

" 1. Name of building struck, and for what purpose used.
(A photograph taken after the disaster would be useful.)

" 2. Date and hour of occurrence; name of place and county.

" 3. Description and situation of the building, and height above sea-level.
(Give particulars as to its position with regard to other buildings and high trees, and its propinquity to any wells.)

" 4. Was rain falling when building was struck? If not, did rain precede or follow the stroke, and at what interval?

"5. Was the building provided with lightning-rods? If so, state number, position, height above roof, material (both of rod and staples), shape, sectional area, how finished at top and at bottom, condition of ends after flash, *i.e.*, whether melted or blunted.

(A sketch plan should be made, which should aim at being a sort of Röntgen-ray representation, the metal-work being shown a different shade from the brick and stone work.)

"6. Was the conductor continuous? Describe the earth-connection. When was the conductor last examined and tested? Has the building been previously struck?

"7. Nature of soil.

"8. State fully the effect on the building; if any portion was set on fire; also if any damage occurred to metal-work, such as bells, rain-water and other pipes, electric bells or telephones, &c.

"9. State distance (vertical and horizontal) of any portion of the building affected by the lightning from the nearest point of the conductor. (If stones, &c., were displaced, state to what distance.)

"10. State materials of roof coverings, and position of gutters and down-pipes. Was the conductor in contact with any other metal?

"11. Were there any metal cresting, weathercocks, finials, or flagstaffs? If so, state distance from and height above conductor.

"12. If the conductor was struck, state whether the damaged portions can be obtained for examination."

CHAPTER II.

CHARACTERISTICS OF A FLASH OF LIGHTNING.

A THUNDERCLOUD is a mass of vapour charged with electricity at a pressure or potential differing considerably from that of the land or waters beneath or the clouds near it—when the difference of electrical pressure between the oppositely electrified cloud and earth or cloud and cloud is sufficiently great an electric discharge of a disruptive nature takes place across the air space which separates them. Clouds are imperfect conductors, and therefore do not part with all their charge at once; there may be several successive discharges. It has been proved by experiment that there are two important classes of lightning flashes, and that it is very necessary to distinguish between them, as the system of lightning rods which will protect from one class of flash may not be able to shield the building from injury by the other class.

This opinion has been adopted by the Lightning Research Committee, who state as follows in their report of April 10th, 1905:—

"It has been pointed out by Sir Oliver Lodge that lightning discharges are of two distinct characters, which he has named the A and the B flashes respectively. The A flash is of the simple type which arises when an electrically charged cloud approaches the surface of the earth without an intermediate cloud intervening, and under these conditions the ordinary type of lightning conductor acts in two ways: first, by silent discharge; and secondly, by absorbing the energy of a disruptive discharge. In the second type, B, where another cloud intervenes between the cloud carrying the primary charge and the earth, the two clouds practically form a condenser; and when a discharge from the first takes place into the second the free charge on the earth side of the lower cloud is suddenly relieved, and the disruptive discharge from the latter to the earth takes such an erratic course *that no series of lightning conductors of the hitherto recognised type suffice to protect the building.*

"On the 28th May last an interesting demonstration of the action of A and B flashes respectively was given by Sir Oliver Lodge before

members of the Committee and others interested in these researches. A thin sheet of metal mounted on non-conducting standards represented the cloud, which was charged at will from Leyden jars and a Wimshurst machine. The 'cloud' was so arranged that the model lightning conductors could have their points brought nearer to or further from its under-surface by shifting their positions on the table. Conductors of copper, iron, and wet string were experimented with. The disruptive discharge to the copper proved to be by far the loudest and most intense of the three. The iron took the flash with less noise, the wet string with hardly any; yet when the discharge passed through it the other and apparently better conductors were not affected. The experiments tended to demonstrate that iron is in many situations a very useful material for lightning-rods, as the effective energy of a flash of lightning is rapidly dissipated in iron. This metal, however, unfortunately oxidises rapidly in towns and smoky districts, and the use of copper is still recommended for main conductors in relatively inaccessible positions as a material for a lightning-rod, though iron is electrically preferable.

"A consideration of the descriptions of recent foreign practice given in Appendix B,* and of the cases which appear in the summary of damage [Appendix A], justifies the following general observations.

"It is probable that with few exceptions buildings in this country are not in reality efficiently protected against the effects of a B flash, although in many cases the lightning conductors may be said to have at least partially fulfilled their purpose by carrying off the more violent portion of a discharge, and that without them greater damage would have occurred in many of the cases reported.

"Some of these observations throw a very interesting light on the effects due to the oscillatory character of lightning discharges. For instance, a discharge takes place over a lightning-rod which may be in contact with, or approach closely to, the metallic portions of a roof. Powerful electrical oscillations are set up in the latter conductors, and dangerously high electrical pressure may be generated on the distant ends of these conductors. If at these points they were connected to earth the pressure would be relieved, and the discharge harmlessly dissipated. Without this safe path the discharge may break away into the down pipes or may pierce the roof to reach internal conductors. Cases which appear to indicate successive or simultaneous flashes may be due to a single flash setting up these oscillations.

"In some cases the damage done to a building by an A flash is not necessarily due to the primary discharge. A lateral discharge occasionally occurs, which frequently causes minor, though in some cases serious, damage owing to falling materials.

"Many of the reports of damage to unprotected buildings show that the lightning discharge followed the path of wire ropes, metallic pipes,

* A summary of these Reports will be found at page 50.

and other conductors, and that the damage to the structure occurred at the breaks in continuity at the upper and lower terminals respectively.

"It may be considered that a lightning conductor of the ordinary type, if properly constructed, affords an undefined area of protection against A flashes; but it cannot be said to have any protective area against B flashes.

"Absolute protection of the whole of a building could only be assured by enclosing the structure in a system of wirework—a contrivance, in fact, of the nature of a birdcage. This should be well connected at various points to earth, as nearly all buildings have gas and water pipes and other metallic conductors in their interiors which are likewise earthed. For structures intended for the manufacture or storage of gunpowder and other explosives the adoption of this birdcage protection would be justified on the score alone of public safety. Architectural considerations prevent the adoption of such a method in its entirety for ordinary buildings. There is no doubt, however, that practically perfect protection may be assured by a judicious modification of the existing practice of erecting single lightning-rods, especially in the case of extensive and lofty buildings that project well above surrounding structures, or that stand isolated in the open country.

"It is obvious that the extent to which the building should be protected, and the expense to be incurred in this protection, must bear some definite relation to the importance or cost of the building itself. In cases where protection is considered desirable, but heavy expense is not justified, two or more lightning-rods might be erected in the ordinary manner, these being connected by a horizontal conductor, and the metal portions of the roof and the rain-water down pipes should be metallically connected and well earthed.

"Tall chimney shafts are not efficiently protected against a B flash by an ordinary single lightning-rod, as a hot column of smoke issuing from a chimney conducts as well as or even better than a rod. A circular band should surround the top of the shaft; four or more conductors should be raised above the latter in the form of a coronal, or the Continental practice of joining the elevation rods together, so as to form an arch over the chimney, may be employed with advantage. One or, preferably, two lightning-rods should extend from this circular band to the earth in the manner described below.

"As most buildings contain systems of gas and water pipes, a good earth for lightning conductors is highly desirable. In the case of a stove inside a building with a metallic stove-pipe carried outside, the stove should be earthed, and a wire be led from the pipe to earth outside, or to the nearest conductor.

"The various cases noted by the Committee show that, while even single conductors tend to diminish the damage done to buildings by lightning, no reliance can be placed on an area of protection. Judging by the latest foreign practice Continental experience appears to be con-

firmatory of this view (see GERMANY, HOLLAND and HUNGARY).* In churches and other buildings with spires and towers the lower projections should also be protected, even if forming part of the salient features of the building.

"No cases of damage to modern steel frame structures have come under the notice of the Committee. The ordinary method of construction, however, in this country does not provide full protection. In many cases the steel columns stand on stone foundations, and the metal is not carried deep enough for effective earthing. The metal columns ought to be earthed at the time of construction."

†Fig. 2 shows the steady strain of the A class. Figs. 3, 4 and 5 are varieties ot the impulsive rush of the B class, where a spark at A precipitates a spark at B, the place where B occurs

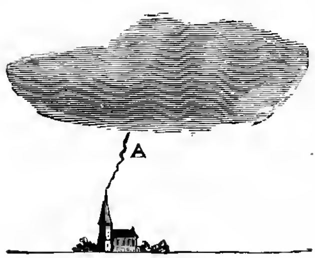

FIG. 2.

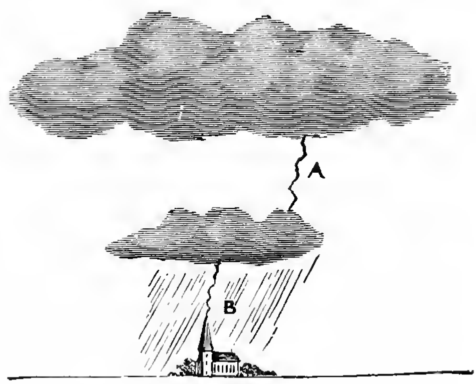

FIG. 3.

having been subjected to no preliminary strain. The rain shower shown in Fig. 5 represents a leak which facilitates the discharge, but is not absolutely necessary.

With the A flash the difference of pressure is gradually established between the clouds and the earth; in this case pointed conductors are efficient protectors, but it is doubtful whether they can protect other points at a lower altitude than they are themselves. The glow discharge which takes place from all the salient upper parts of a building, and notably from the air terminals of the lightning rods, seems to prepare the path of the discharge towards itself and neutralises its force. The heated air from a chimney acts in a somewhat similar manner, and will conduct the

* A summary of these Reports will be found at page 50.

† This is an abstract of the experiments, more extensively illustrated and described in full in "Lightning Conductors," Lodge, 1902.

discharge to the stove or source of heat in a dangerous manner, if it is not in connection with the earth. The lightning rod if properly installed should prevent this deviation.

With the B flash the neutralising effects of the points is not so marked as with the A discharge, and the lightning may

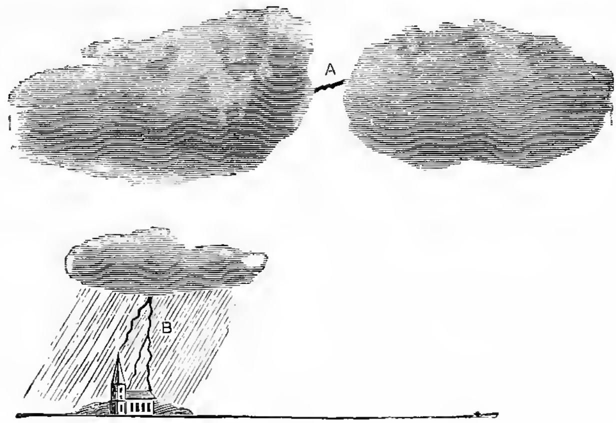

FIG. 4.

strike any salient part of the building, and to guard against damage it is necessary to imitate the cage or meat-safe protection suggested by Clerk Maxwell,* and experimented with by Lodge,

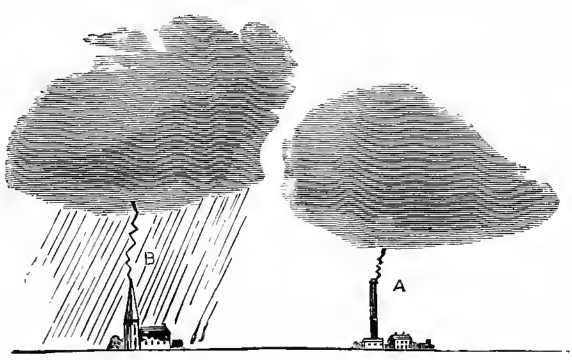

FIG. 5.

who showed that if two wires are let into a gauze house it was impossible to obtain a spark between these points whatever flashes pass alongside, and suggested that barbed iron wire might be run about and over a building, and thus enclose it in a

* *Phil. Magazine, August,* 1889.

lightning-proof cage. Architectural and other questions prevent the adoption of this simple plan, but there is no reason why iron wire should not be run in such a manner along the ridge, over and across the roofs, and joined to the guttering, rain-water pipes and other metal work, which would, as well as the special down conductors, be earthed, so that a skeleton cage would surround the building, and thus carry out in practice what many scientists have advocated in theory. The author has given some attention to this method of protection, which will be found described at page 28.

The two main destructive aspects of a lightning flash are—(1) its disruptive or expanding and exploding violence; (2) its heating effect.*

In Germany two kinds of strokes have been recognised for some time, one as "Zündenden" (fire causing), probably the B flash, and the other, known under the name of "Kalten" (not causing fire), is the ordinary A discharge.

"The heating effect is more to be dreaded when the flash is slow and much resisted; the bursting effect when conducted well except at a few places. Conducting the charge to earth is no secure mode of getting rid of the energy, and unless the energy is exhausted the charge will rise up again, and so may swing up and down a good many times before the store of energy is all gone; and nothing can be worse as regards disruptive effect than this repeated and violent passage of an enormous electric current."†

The disruptive effect is well shown when trees are struck by lightning; their appearance afterwards is as if every cell were burst by the expansion in the path of the discharge, and sometimes where timber such as is found on old churches is rent by lightning, it is simply disintegrated, as if it had been pounded in a pestle and mortar.

There is reason to believe that lightning sometimes strikes an object with a whirling blow, and this may be the reason for the shifting of blocks of masonry, which are sometimes found out of position when the building of which they formed part has been struck.

One occasionally hears of what is popularly termed a fire-ball exploding in the act of falling on a certain spot. This is probably the result of a B flash striking the ground, which will be generally found to be opened up as if a circular tool had been used. The

* See R.I.B.A., Parnell, 1884. † Lodge.

ground round a tree which was struck at Blanefield, Stirlingshire, in 1903, was covered with holes of about five inches diameter, which appeared to have been drilled; the holes, which were often connected by shallow furrows, were more numerous in the direction away from the brook, where the main portion of the flash went to earth. Trees are often found with the bark ringed in a spiral fashion. If a lightning flash has a rotary movement, the formation of those curious masses of vitrified sand, called fulgurites,* is more readily explained. In mountainous districts holes are found smoothly bored in the solid rocks, and this action appears also to be due more to the whirling of the flash, than its disruption at the moment of striking an object of such high electrical resistance.

Although it has not been conclusively proved that lightning is oscillatory it is easier to explain its action on this supposition, and the reason why ordinary conductors are so frequently liable to lateral discharge, is that they are constructed on the incorrect assumption that lightning obeys the same laws as a constant electric current. The old views were, as if something had to be allowed to escape or let down like rain, or as if a certain amount of stuff, called "electrical discharge," had to be got rid of, and all one need do was to provide an easy channel to earth, down which it would travel avoiding all other paths. It was also supposed that the easiest way to disperse the electricity one did not want was to supply it with the best possible conductor, in fact, the largest one could afford, and the only reason for not using a copper rod a foot thick was that of expense. But it is now known that a copper rod of this area would be dangerous, and a number of iron wires one-tenth of an inch in diameter would be much safer. Why is this, that copper, which is one of the best conductors of electricity, is not so suitable for the purpose of protection from lightning as iron? The answer is—Because of electrical inertia. "Suppose you have a pipe or tube full of water, used as a perpetual overflow to a cistern, and you want it to be equal to all demands. You test it, and find it perfectly easy to pour the water either way—both ends are perfectly open; the pipe is a good conductor. Then comes someone and hits the

* See page 91.

NOTE.—The letters L.R.C. mean Lightning Research Committee.—AUTHOR.

stagnant water in your pipe a tremendous blow with a hammer, bursts the pipe, and scatters the water about. That is what lightning does to your lightning conductor and to the electricity in it. It is no gentle push, but a terrific blow."* A copper rod allows the discharge to pass too quickly, and produces a shock of the utmost violence; in fact, in experiments recently shown at the Royal Institution of British Architects to the Lightning Research Committee by Sir Oliver Lodge, the large copper conductor, which was perfectly earthed, gave out sparks of great intensity, and these, if a lightning discharge had been passing, would have been quite sufficient to set fire to the building. An iron conductor offers more impedance to the current and allows it to leak away by damping the so-called oscillations, so there is less chance of a side flash from an iron than a copper conductor.

In other words, if a large copper rod is used, the self-induction of the current is increased, a factor, which, although its effects cannot be exactly defined, is shown by actual experiments to exercise frequently a powerful influence. Since self-induction has a paralysing effect upon the passage of the current, it should be reduced to the smallest possible limits in the system of conductors; for this reason unnecessary bends in the rods should be avoided, and they should be kept specially free from abrupt turns. To understand this action, one should refer to Lodge's experiments and the examples contained in several manuals of physical science,† showing that a discharge from a Leyden jar prefers to make its way through the air rather than follow the spiral coils, even of a thick copper wire.

In protecting buildings from lightning we must bear in mind that it does not follow the law of electric currents such as we are familiar with, or those we read about as being employed for long distance power transmission.

1. Lightning shows a great tendency to distribute itself over such conductors as may be present on a building, and in doing so pays little heed to ohmic resistance.
2. It finds no great difficulty in making its way, often for a considerable distance, through the air or any other medium of rather better conductivity.

* "Lightning Conductors," Lodge, pp. 20 and 33.

† "Y le Roy," Vol. III., p. 90.

3. It prefers as much as possible to move in a straight line, and that therefore sharp turns, bends, or spiral windings in conductors present hindrances which readily lead to lateral discharges.

AREA OF PROTECTION.

It is curious to note the growth of this fallacy, which was first dispelled by Lodge at the Bath meeting of the British Association, and has received its death blow by the Report of the Lightning Research Committee, which contains many examples of buildings struck in the so-called protected area. Franklin does not mention the shielding effect of a lightning rod, but relies on its attraction,* and it is probable that from his remarks the Academy of Science (in 1823) evolved the "protected space," to which they gave the name of the "double cone of Charles," in other words, a cone having for its apex the top of the lightning rod, and for its base a circle with a radius equal to twice its height. Later on Guy Lussac introduced M. Charles' single cone—*i.e.*, a similar cone having a base with a radius equal to only once the height—for church towers of ordinary height. In 1855 the double cone, which had meanwhile been found to be unsatisfactory in practice, was replaced by one having a base of $1\frac{3}{4}$ height radius. The Lightning Rod Conference in 1882 practically supported the rule that the base of the protected cone is assumed to have a radius equal to the height from the ground, but at the same time added, "though this may be sufficiently correct for practical purposes, it cannot always be relied on."

Sir Oliver Lodge considered the term area of protection meaningless, and states:—"There is no space near a rod which can be definitely styled an area of protection, for it is possible to receive violent sparks and shocks from the conductor itself, not to speak of the innumerable secondary discharges that are liable to occur as secondary effects in the wake of the main flash."†

In the recently issued rules for the protection of Admiralty structures, the cone theory is dismissed with the following remark:—"This statement is not now generally accepted as true.

* See extract, "Franklin on Lightning Rods," p. 105. † Lodge, p. 190.

Buildings protected on this principle would require very lofty lightning rods." It is considered that a number of smaller rods well connected together by conductors, carried along the salient features of a building, provide a more reliable protection than an equal amount of metal in higher rods spaced at greater intervals, and this is the system that has been adopted for the protection of all Admiralty structures.

The area of protection afforded by a conductor depends much more on the efficiency of the earth connection than upon the height of the terminal point, and if thorough protection be desired for any building, it is necessary to put a conductor or conductors upon it. For instance, at Coatbridge Church, Report No. 93, there were a number of balusters on a tower. The lightning conductors ran up one of these and encircled the base of all the others, yet the stroke destroyed three of the balusters, and fused part of the horizontal conductor, on its way to earth by the adjacent rod. If each of the balusters had been furnished with a conductor, say less than one quarter of an inch in diameter, connected to this horizontal cable, the protection would have been ample.

The Elektrotechnische Verein, issued in 1900 and 1901 two pamphlets on dangers from lightning, and do not even mention the idea of a protected area, which is practically abandoned.* Dr. Van Gulik, in his report, 1905, to the Dutch Academy of Science, says:—"The days of the Lightning Rod Conference and Guy Lussac are past and gone; we no longer guarantee absolute security, but can only say that the protection afforded is more or less good according to whether the system adopted conforms with the principles which science has shown to be correct. The means by which protection is secured and the outlay required depends to a large degree on the value attached to the preservation of a building from damage great or little."†

* "Elektrotechnische Zeitschrift," 1900, p. 340. † Haarlem, 1905.

PREFACE TO THE FIRST EDITION.

"The Phœnix Fire Office Rules" for the Erection of Lightning Conductors have been drawn up after consultation between Sir Oliver Lodge, D.Sc., F.R.S., Principal of the University of Birmingham, Mr. Killingworth Hedges, M.Inst.C.E., M.I.E.E., Hon. Sec. to the Lightning Research Committee, 1901 to 1905, and Mr. S. G. Castle Russell, M.I.E.E., Electrical Adviser to the Phœnix Assurance Company, Limited.

March, 1910.

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"THE PHŒNIX FIRE OFFICE RULES"

FOR

LIGHTNING RODS.

IDEAL METHOD OF PROTECTION.

In the Report issued by the Lightning Research Committee in 1905, it is pointed out that lightning discharges are of two distinct characters, named the "A" and "B" flash respectively. The "A" flash is of simple type; it can be prevented, or its violence diminished, by the silent discharge which goes on during a storm from various points of a building. Its path is prepared beforehand by ordinary electrostatic considerations, and it strikes pointed conductors in preference to others. The usual system of two or more conductors, if properly constructed, affords sufficient protection against a flash of this kind.

The "B" flash is a disruptive discharge of much greater suddenness, which falls on a building without preparation; it may strike the building in several places at once, and is no more likely to select points than knobs. A column of hot air, like that of a chimney, is the path most favoured by this kind of discharge. Points are no protection against it; the only way to obtain absolute security is to enclose the structure in a metal framework, constituting what has been described as the "bird-cage" system of conductors.

In a modification of this system for an ordinary building, a sufficient practical approach to ideal conditions can be attained by taking advantage of the extent of metal work outside it, and adding a few other conductors, so as to surround it and imitate roughly a metallic enclosure. Under expert supervision this can generally be accomplished by utilising the rain water pipes and gutters as part of the system. Joints in the pipes and gutters act more securely when bonded together, or made electrically continuous. The ordinary conductors must be fixed in addition, and the whole system of pipes, etc.,

together with the special conductors may, advantageously, be interconnected by a horizontal conductor taken round the buildings, either two or three feet above the ground level or buried in the ground.

The complete system should then be efficiently connected to earth at several places.

A building with trees adjacent to it, or dominated by a steeple or other lofty building must not be considered as immune. A discharge is seldom solitary, along one single path ; it is often an assemblage or bush of flashes, and all points in the neighbourhood are liable to be struck by some of the subsidiary or accompanying discharges. Even underground cellars have been so invaded.

RULE No. 1.—CONDUCTORS.

Material of Conductor.

Material should be of copper tape at least 1 inch by $\frac{1}{8}$th inch, or of a stranded copper rope of not less area ; no cable to be smaller than that composed of seven strands, each of $\frac{1}{8}$th inch diameter, or of soft iron cable, properly galvanised or sheradized ; the total sectional area of iron cable need not be greater than that of copper, except for chemical reasons and permanence. In inaccessible places, and atmospheres where chemical corrosion may be feared, copper should be used of larger sectional area than 1 inch by $\frac{1}{8}$th inch.

Copper conductors are generally accepted as being more lasting and less subject to deterioration by atmospheric influence, etc., although iron is electrically more efficient than copper, since it carries off the discharge with less tendency to disruptive effect. Any conductors may be given a protective coat of paint—painting or otherwise coating a conductor does not detract from its efficiency.

Method of Running.

Conductors should be run in as direct a line to earth as convenient, and sharp bends and joints avoided ; they should be kept a certain distance away from the walls. The object of keeping conductors a certain distance away from walls is to prevent accumulation of dirt, and to avoid sharp bends when passing over cornices, etc., but they must not be insulated from the walls.

Conductors should, as far as possible, be run in single lengths.

Conductors should be protected at earth level by galvanised iron

tubing or casing carried 5 feet above the surface ; this casing should be made watertight where the conductors enter and leave.

Conductors running underground and connected to the earth plate or tubular earth should be embedded in a wooden trough filled in solid with bitumen to prevent chemical corrosion.

Vertical conductors should be connected to all the metal work on the roofs, such as rain-water pipes and gutters, metal roofs, flashings, ridgings, finials, cowls, etc. All exposed metal work on the outside of the building should form with the conductors a complete network. As far as practicable it is desirable to connect the conductors to exposed and elevated masses of metal, such as church bells and metal clocks ; or it may be preferred to protect clocks by providing a sufficiency of outside conductors to act as a screen, which should be inter-connected and carried to a sufficient number of earth connections.

Conductors must be kept at least 12 ft. from all gas pipes and from the meter, the ingoing and outgoing service gas pipes should be connected together by a short piece of metal.

All telephone wires, or any exposed system of wires entering the interior from the outside, must be provided with a special lightning guard or arrester where they enter.

Joints in Conductors.

For tape conductors all joints must be carefully soldered and made electrically and mechanically continuous, screwed together or clamped. Stranded cable conductors should be connected by linesman's joints and soldered or united by a special joint box. After the strands of the cable are twisted together, the box should be filled in with molten solder.

RULE No. 2.—ELEVATION RODS.

Elevation rods should be of solid copper or galvanized iron of ample section and fixed at least two feet above that portion of the building to which they are attached, by a sleeve joint soldered and pinned, or by means of a box joint filled with solder and pinned. In the case of chimney stacks the rod must be at least one foot above the highest chimney in the group which forms the stack.

The elevation rod should have three or more points which must be firmly screwed into a solid casting, or it could be united by a box containing pockets which receive the points, the whole being filled with solder.

RULE No. 3.—HOLDFASTS.

Holdfasts should be of gun-metal or brass for copper conductors or of malleable iron for iron conductors and let into the wall in such a manner as to support and keep the conductor away from the structure at such a distance as will avoid anything like sharp bends round cornices and projections.

Rule No. 4.—NUMBER OF CONDUCTORS AND AREA OF PROTECTION.

This depends on the size of the building and the comparative heights of its structural parts. There is no special area below an elevation rod which can be considered as actually protected; so that "area of protection" really cannot be defined, and no definite rule can be laid down as to the number of rods necessary to protect a building. The consideration of the extent of protection afforded must bear some relation to the value and importance of the building concerned. It should be the practice to provide at least two or more rods on any building. The best known system of protection is referred to on the first page.

It should be noted that any chimney stack is liable to be struck; each, therefore, should have its own elevation rod connected to the nearest conductor leading to earth. Special attention should be paid to kitchen chimneys, as a column of hot air will often be selected as a path for the flash.

RULE No. 5.—EARTH CONNECTIONS, AND NUMBER.

The earth connection should be made either by means of a copper plate buried in damp earth, or by the tubular earth system, or by connection to the water mains. The number of connections should be in proportion to the ground area of the building, and there are few structures where less than two are necessary; if it is thought desirable to use the modified "birdcage" system, described on page 1, each side of the building should have its own earth. Church spires, high towers, factory chimneys, etc., having two down conductors should have two earths, which may be inter-connected.

If a copper plate is used it should not be of less than 3 sq. ft. in area and not less than $\frac{1}{8}$th inch thick, and rectangular in shape, with saw

edges and surrounded with broken coke or graphite. If coke is used it must be thoroughly washed to eliminate any sulphur which may destroy the copper. The conductor should be firmly attached so as to make a permanent mechanical, and electrical, joint.

The earth connections should be kept at least 12 feet from gas mains.

The use of copper plate is not recommended unless it can be sunk into the earth at such a depth as to ensure it always being in water or in moist earth.

The tubular earth system is as follows, and is recommended for use where the ground cannot be disturbed for burying a plate, or where permanent moisture is at a considerable depth. A perforated pipe, furnished with a steel spike is driven into the ground until it reaches moisture, and then lengthened up to the surface, to a casting which marks the position of the earth. The copper conductor is enclosed in the pipe, and carried to the bottom of the tube which is packed with granulated carbon. A connection is made by means of an iron or lead pipe to the nearest rain-water pipe, so that a small quantity of rain is diverted to insure moisture, or a similar pipe may be opened up into a funnel shape at the surface of the ground, so that rain will enter, or water can be poured down.

Where conditions permit connection to a water main, that is a satisfactory plan, provided that the main is not insulated by hydrant joints, or periodically disconnected.

RULE No. 6.—TEST AND EXAMINATION OF EARTH CONNECTIONS.

The earth resistance of each of the earth connections should not exceed 5 ohms. For the purpose of testing, a special disconnection joint should be made in the conductor near the ground level, so that the earth can be tested separately from the system of the conductors on the building by disconnecting the joint.

A test and examination should be made once annually by a competent expert.

RULE NO. 7.—SPECIAL RISKS.

Churches.

In the case of Churches or Buildings having long roofs, and where more than one conductor is used, the down rods should be connected together by a horizontal rod (fitted with aigrettes say from 20 to 30 ft.

apart) running along the ridge or flat of the roof, and held about three inches away by holdfasts. From this rod subsidiary conductors should be run to earth. All exposed and elevated masses of metal, such as church bells and metal clocks should be connected with the conductors.

Factory Chimneys.

In the case of factory chimneys the elevation rod should take the form of a circular band of metal round the top of the shaft, preferably below the actual outlet and furnished with long spikes. The points should be fixed at an angle of about 45 degrees, pointing outwards; or an arch of metal, provided with points, may be fixed across the mouth of the chimney.

Two vertical conductors at least, kept away from the brick wall by holdfasts, should be carried down to a thorough "earth"; and if there are two earths, as is preferable, they should be connected by a metal band.

If a factory chimney has an internal metal shaft part of the way up, this should be well earthed at the bottom but should not be connected to or form part of the lightning conductor system which is intended to receive and carry off the flash.

After a Church or other uninhabited building has been struck by a flash, or whenever there has been a flash in the near neighbourhood, it should be carefully examined and attended to for some time to see that no actual ignition of gas has occurred, owing to the puncture of a compo pipe by a residual spark causing and igniting an accidental leak; for such a trifling flame, if unattended to, may spread.

Every building in the immediate neighbourhood of a flash is liable to such small residual sparks: they can occur even between well-earthed systems such as gas and hot water pipes, or where a gas pipe is crossed by a bell wire.

Flagstaffs on Buildings.

Flagstaffs on buildings should be provided with their own conductors efficiently connected to earth, or be connected to the system of lightning conductors erected on the same building.

Church Spires and Lofty Towers.

These should preferably be protected by two conductors.

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CHAPTER III.

THE LIGHTNING RESEARCH COMMITTEE'S SUGGESTIONS AND RULES, 1905.

THE Lightning Research Committee in their report put forward the following suggestions for practice, which are the result of their investigations:—

1. Two main lightning rods, one on each side, should be provided, extending from the top of each tower, spire, or high chimney stack by the most direct course to earth.
2. Horizontal conductors should connect all the vertical rods (*a*) along the ridge, or any other suitable position on the roof; (*b*) at or near the ground line.
3. The upper horizontal conductor should be fitted with aigrettes or points at intervals of 20 or 30 feet.
4. Short vertical rods should be erected along minor pinnacles and connected with the upper horizontal conductor.
5. All roof metals, such as finials, ridging, rain-water, and ventilating pipes, metal cowls, lead flashing, gutters, &c., should be connected to the horizontal conductors.
6. All large masses of metal in the building should be connected to earth, either directly or by means of the lower horizontal conductor.
7. Where roofs are partially or wholly metal-lined they should be connected to earth by means of vertical rods at several points.
8. Gas pipes should be kept as far away as possible from the positions occupied by lightning conductors, and as an additional protection the service mains to the gas-meter should be metallically connected with house services leading from the meter.

Rules for the Erection of Lightning Conductors, as issued by the Lightning Rod Conference in 1882, with observations thereon by the Lightning Research Committee, 1905.

NOTE.—SOME OF THE LIGHTNING ROD CONFERENCE RULES ARE OMITTED; THOSE WHICH HAVE BEEN RETAINED ARE PRINTED IN ITALICS.

(1.)—UPPER TERMINALS.

The number of conductors or points to be specified will depend upon the size of the building, the material of which it is constructed, and the comparative height of the several parts. No general rule can be given for this; but the architect must be guided by the directions given. He must, however, bear in mind that even ordinary chimney stacks, when exposed, should be protected by short terminals connected to the nearest rod, inasmuch as accidents often occur owing to the good conducting power of the heated air and soot in the chimney.

It is not necessary to incur the expense of platinising, gilding, or electroplating. It is desirable to have three or more points beside the upper terminal, which can also be pointed; these points must not be attached by screwing alone, and the rods should be solid and not tubular.

(2.)—INSULATORS.

The rod is not to be kept from the building by glass or other insulators, but attached to it by metal fastenings.

This is dealt with by Suggestion 3, page 15.

(3.)—FIXING.

Rods should preferentially be taken down the side of the building which is most exposed to rain.

In most cases it would be advantageous to support the rods by holdfasts (which should be of the same metal as the conductor) in such a manner as to avoid all sharp angles. The vertical rods should be carried a certain distance away from the wall to prevent dirt accumulating, also to do away with the necessity of their being run round projecting masonry or brickwork.

(4.)—FACTORY CHIMNEYS.

These should have a copper band round the top, and stout, sharp copper points, each about one foot long, at intervals of two or three feet throughout the circumference, and the rod should be connected with all bands and metallic masses in or near the chimney.

As an alternative the rods above the band might with advantage be curved into an arch provided with three or four points. It is preferable that there should be two lightning-rods from the band carried down to earth in the manner previously described. Oxidation of the points does not matter.

(5.)—ORNAMENTAL IRONWORK.

All vanes, finials, ridge ironwork, &c., should be connected with the conductor, and it is not absolutely necessary to use any other point than that afforded by such ornamental ironwork, provided the connection be perfect and the mass of ironwork considerable. As, however, there is risk of derangement through repairs, it is safer to have an independent upper terminal.

Such ironwork should be connected as indicated in Suggestion 5. In the case of a long line of metal ridging a single main vertical rod is not sufficient, but each end of the ridging should be directly connected to earth by a rod. Where the ridge is non-metallic a horizontal conductor (which need not be of large sectional area) should be run at a short distance above the ridge and be similarly connected to earth.

(6.)—MATERIAL FOR ROD.

Copper, weighing not less than 6 ounces per foot run, either in the form of tape or rope of stout wires—no individual wire being less than No. 12 B.W.G. Iron may be used, but should not weigh less than 2½ lbs. per foot run.

The dimensions given still hold good for main conductors. Subsidiary conductors for connecting metal ridging, &c., to earth may with advantage be of iron and of a smaller gauge, such as No. 4 S.W.G. Galvanised Iron. The conductivity of the copper used is absolutely unimportant, except that high conductivity increases the surges and side flashes, and therefore is positively objectionable. It is for that reason that iron is so much better.

(7.)—JOINTS.

Although electricity of high tension will jump across bad joints, they diminish the efficacy of the conductor; therefore every joint, besides being well cleaned, screwed, scarfed, or riveted, should be thoroughly soldered.

Joints should be held together mechanically as well as connected electrically, and should be protected from the action of the air, especially in cities.

(8.)—PROTECTION.

Copper rods to the height of 10 feet above the ground should be protected from injury and theft by being enclosed in an iron pipe reaching some distance into the ground.

(9.)—PAINTING.

Iron rods, whether galvanised or not, should be painted; copper ones may be painted or not, according to architectural requirements.

(10.)—CURVATURE.

The rod should not be bent abruptly round sharp corners. In no case should the length of the rod between two points be more than half as long again as the straight line joining them. Where a string course or other projecting stone work will admit of it, the rod may be carried straight through, instead of round the projection. In such a case the hole should be large enough to allow the conductor to pass freely, and allow for expansion, &c.

The straighter the run the better. Although in some cases it may be necessary to take the rod through the projection, it is better to run outside, keeping it away from the structure by means of holdfasts, as described above. See Fig. 6.

(11.)—EXTENSIVE MASSES OF METAL.

As far as practicable it is desirable that the conductor be connected to extensive masses of metal, such as hot-water pipes, &c., both internal and external; but it should be kept away from all soft metal pipes, and from internal gas-pipes of every kind.

It is advisable to connect church bells and turret clocks with the conductors. See Suggestion 8.

(12.)—EARTH CONNECTION.

It is essential that the lower extremity of the conductor be buried in permanently damp soil; hence proximity to rain-water pipes, and to drains, is desirable. It is a very good plan to make the conductor bifurcate close below the surface of the ground, and adopt two of the following methods for securing the escape of the lightning into the earth. A strip of copper tape may be led from the bottom of the rod to the nearest water main—*not merely to a lead pipe—and be soldered to it; or a tape may be soldered to a sheet of copper 3 feet by 3 feet, at least $\frac{1}{16}$ inch thick, buried in permanently wet earth, and surrounded by cinders or coke. Where iron is used for the rod, a galvanised iron plate of similar dimensions should be employed.*

The use of cinders or coke appears to be questionable, owing to the chemical or electrolytic effect on copper or iron. Charcoal or pulverised carbon (such as ends of arc-light rods) is better. *Instead of the plates there are advantages in using* a tubular earth consisting of a perforated steel spike driven tightly into moist ground and lengthened up to the surface; the conductor reaching to the bottom and being packed with granulated charcoal, gives as much effective area as a plate of larger surface, and can easily be kept moist by connecting it to the nearest rain-water pipe. The resistance of a tubular earth on this plan should be very low and practically constant.

(13.)—INSPECTION.

Before giving his final certificate the architect should have the conductor satisfactorily examined and tested by a qualified person, as injury to it often occurs up to the latest period of the works from accidental causes, and often from the carelessness of workmen.

Inspection may be considered under two heads:—

A. The conductor itself.

B. The earth connection.

A. Joints in a series of conductors should be as few as possible. As a rule they should only be necessary where the vertical and horizontal conductors are connected, and the main conductors themselves should always be continuous and without artificial joints. Connections between the vertical and horizontal conductors should always be in places readily accessible for inspection. Visible con-

tinuity suffices for the remainder of circuit. The electrical testing of the whole circuit is difficult, and needless.

B. The electrical testing of the earth can in simple cases be readily effected. In complex cases, where conductors are very numerous, tests can be effected by the provision of test clamps of a suitable design.

(14.)—COLLIERIES.

Undoubted evidence exists of the explosion of fire-damp in collieries through sparks from atmospheric electricity being led into the mine by the wire ropes of the shaft and the iron rails of the galleries. Hence the headgear of all shafts should be protected by proper lightning conductors.

The two methods of running a conductor are illustrated by Fig. 6. **A** is that recommended in Rule 10 by the L.R.C., holdfasts being used to keep the tape or cable away from the structure. **B** is the old method, which is condemned.

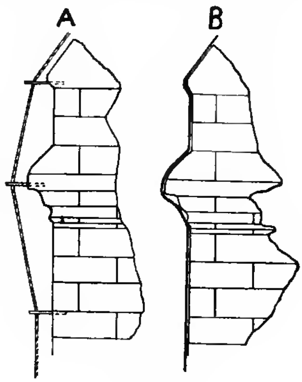


FIG. 6.

SIGNED BY—

JOHN SLATER, *Chairman.*
E. ROBERT FESTING.
OLIVER LODGE.
J. GAVEY.
W. N. SHAW.
A. R. STENNING.
ARTHUR VERNON.
KILLINGWORTH HEDGES,
Hon. Secretary.

10*th April,* 1905.

CHAPTER IV.

METHODS OF PROTECTION.

THESE may be divided into three heads:—(1st) The Continental, where solid iron rods are generally used; the methods will be found more fully described under Continental Systems on page 57; (2nd) The use of copper cable or tape, with elevation rods on the salient points of the building, connected with a horizontal conductor on the roof; and (3rd) The modified bird-cage plan.

(1.) It is doubtful whether the Continental method, with the high *tiges* or points, will ever find favour with architects here, mainly on account of the strain on the roofs, which necessitates rather complicated arrangements, but also owing to the unsightly appearance of the lengths of iron rods, which do not improve the architectural features of a building.

(2.) It is, however, quite possible to secure all the advantages of the former method (1) without making the conductors so prominent, and the object of the author has been to retain the points on the roofs, but make them so unobtrusive as to be hardly noticeable to a spectator below. To protect a structure, let us commence at the highest point, and there fix four point air terminals or elevation rods. These are made in 3 feet and longer lengths, and are of $\frac{3}{4}$, $\frac{5}{8}$, or $\frac{1}{2}$ inch solid copper, Figs. 7 or 8; or, if in the case of a church having a number of towers or spires, each must have a single point, as Fig. 9. The main conductors may be of cable or tape—the former is preferable—but whichever is used they should be run as nearly vertical as possible from the highest points of the building to earth. All subsidiary conductors from points of similar or lower heights must be connected to the system. It is not advisable to carry a conductor a long distance in order to make this connection; it should be run to a separate earth. The number of these earth connections

must depend on the area occupied by the building; for instance, a church of ordinary design and size would require four "down" rods, that is, one from the spire, one on both sides of the nave, and one at the extreme end. It is advantageous to run two conductors from the top of the spire or tower, one on each side.

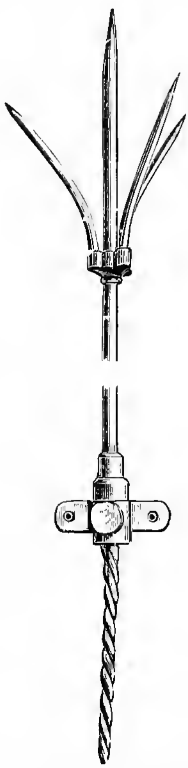


FIG. 7.—3 FT. ELEVATION ROD, WITH POINTS BRAZED TOGETHER, USED WHERE EXPOSED TO MUCH HEAT.

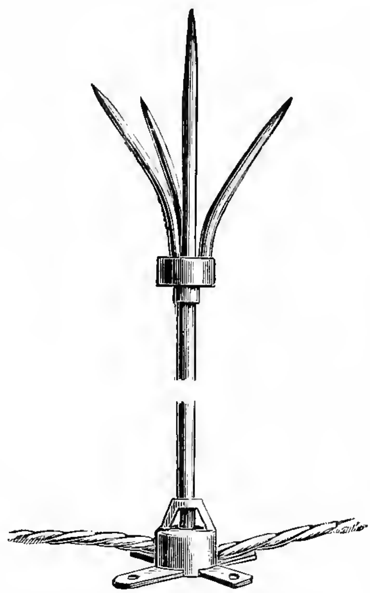


FIG. 8.—ELEVATION ROD FOR HORIZONTAL POSITION OR FLAT ROOF.

FIG. 9.—PLAIN POINT ELEVATION ROD.

Horizontal Conductors (see L.R.C. Suggestion 2, page 15). To complete the system, all the down conductors should be intersected by at least one horizontal rod, with the object of having a path for any side flash or portion of the main stroke which may not be carried away harmlessly by the main rod. Where there is a considerable length of roof, aigrettes (Fig. 11) should be fixed as shown by Fig. 10, which is taken from a model of the roof of Westminster Abbey. The down conductros on their way to earth should be connected to any metal work in the neighbourhood, also to rain-water gutters,

pipes, etc.; the number of these subsidiary down conductors depends on the length of the roof.

At a conference held on behalf of the L.R.C., in April, 1904, Sir Oliver Lodge suggested that these down conductors should, in the case of a church, be run between each of the windows.

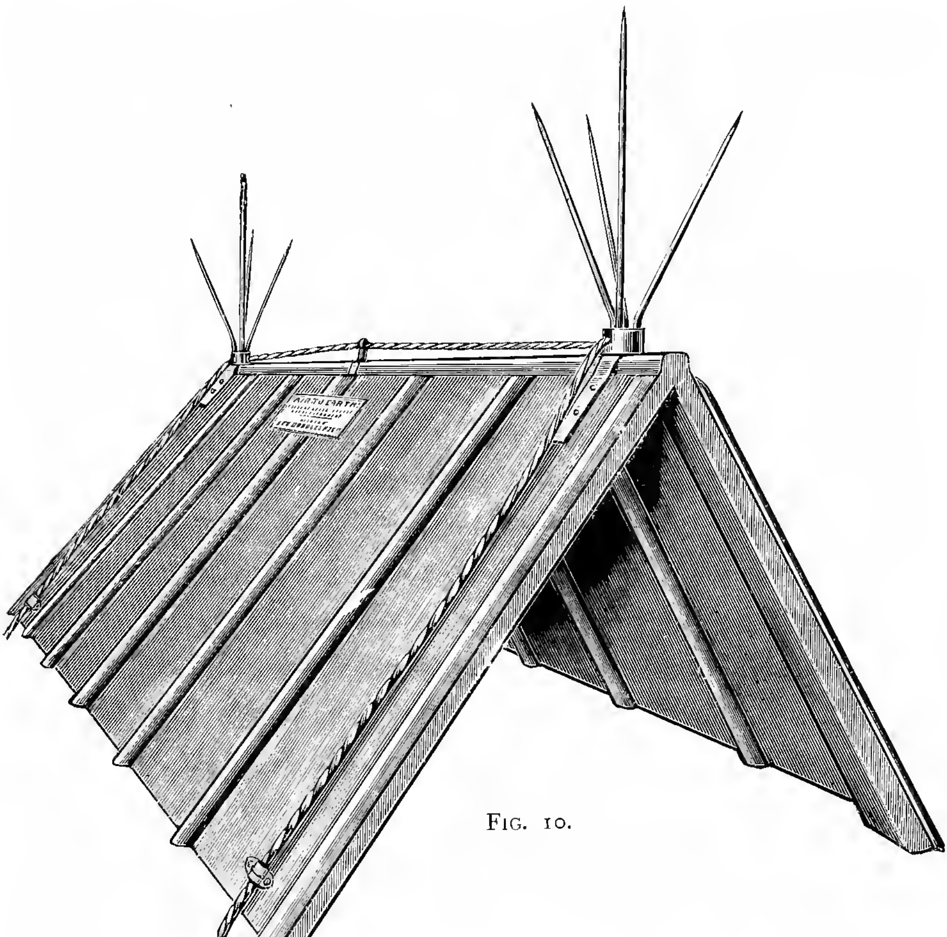


FIG. 10.

Method of running Conductors. These, whether vertical or horizontal, should be kept away from the structure (L.R.C. Rule 10) so as to avoid all sharp bends, and facilitate straining, and secondly, to prevent the corrosion which may take place where the metal is in contact with the brick or stone work. It is found advisable

even to keep the horizontal rod away from good conductors, such as the metal roll of the ridge of a roof, as shown in Fig. 10, as the holdfasts are in electrical contact. These are usually made of brass or gun-metal, and are of various forms; the most usual is as shown by Fig. 12, and is generally employed for vertical rods, one end being let into the brick or stone work and firmly secured. A somewhat similar pattern, but fitted with a Λ base, can be fixed to the lead beading of the ridge, but where

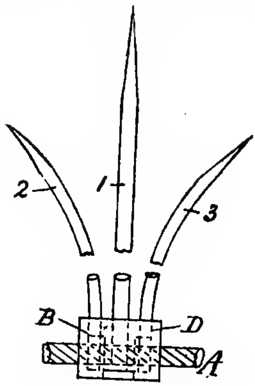


FIG. 11.—AIGRETTE.

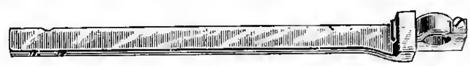


FIG. 12.—ROPE HOLDFAST.

the roof is non-metallic the horizontal conductor can rest on the projections which are often found on ridge tiles; a special kind having a small groove to hold the cable may be obtained.

Joints between the Conductors must be made mechanically as well as electrically (L.R.C. Rule 7), that is, two pieces of cable or tape sweated together might test well when new, but in the course of ten years be found not to be in electrical contact. A simple mechanical joint can be made by using a box, as shown by Fig. 13. This can be used for plain, two-way, up to four-way joints. For a T joint the previously tinned cable is partially opened and the loose end inserted at A^1, as shown by Figs. 14 and 15, if a simple joint is required, the two ends are twisted together, in both examples the cable is laid in the previously heated box and molten solder or pot metal completes the electrical connection. Somewhat similar connecting boxes are used for tape. Fig. 16 shows the plan of a box making a

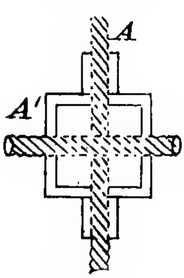


FIG. 13.

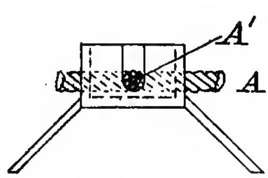


FIG. 14.

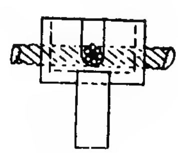


FIG. 15.

T joint. If it is required to connect the cable or tape to a single air terminal, such as are used on chimneys and other points, the conductor is inserted in the lower part of the socket, Fig. 17, and the rod in the top end, and molten solder is poured in to complete the joint. This method of forming a permanent joint is also used for the air terminals or elevation rods. The multiple points are not screwed into a ball, through which the rod passes, as the author has found that the thread deteriorates with age and the points (even the whole top) has been known to fall off. It will be seen by reference to Fig. 8, that the points are secured to the centre point, which is a prolongation of the actual rod, by means of the sleeve, Fig. 18 (*in this figure four points are shown, the centre one being omitted*), which has pockets or recesses in which the points are firmly secured, and the box is filled up with solder; the points are at first kept close together, as shown by Fig. 19, for convenience of transport. An aigrette is made up in a similar manner. Referring to the elevation Fig. 11, the pockets are shown at **B D**, in which the previously tinned ends of the rods 1–2–3 are placed, they are also shown in plan by Fig. 20, and end view Fig. 21; the centre point is inserted in the cable, which is partly untwisted. One advantage possessed by this method of securing the various points to the cable or tape is, that all the joints are made by pouring into the boxes or sockets, the hot pot metal or solder which has been previously melted, so that it is unnecessary to have a "devil" or fire on the roof of the building, as it is

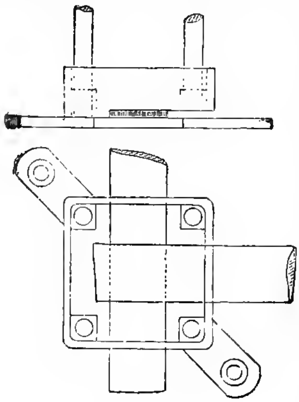


FIG. 16.

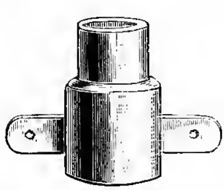


FIG. 17.—CONNECTOR, CABLE TO ROD.

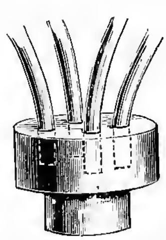


FIG. 18.—SLEEVE.

FIG. 19.

quite easy to quickly hoist the pot of solder, which is enclosed in some receptacle, by means of a pulley to any height required.

Connecting Metal Work.—It would not always be practicable to connect the actual down conductors with all the ironwork or to the rain-water gutters, rain-water pipes and ventilating pipes, so pieces of solid copper wire of, say, No. 10 B.W.G., or two or three strands of the actual copper rope can be used, and be either soldered or clamped to the above. An efficient plan is to use a metal socket, which is sweated to the copper cable, and is fastened to the object by means of a bolt which passes through an eye formed on the opposite end to the socket.

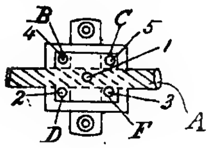


FIG. 20.

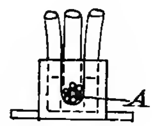


FIG. 21.

Pipes can be connected by means of a clamp, but care must always be taken to prevent galvanic action between the metals which are joined together, and as this action is greatly hastened by damp, the connections must never be in a position where water will collect. Fig. 22 is an end view of the hollow clamp B², round the pipe F². Lead is poured through the hole C², and before it is solidified the clamp is tightened by the screws G². In some cases the cable or tape can be twisted round the pipe, and be soldered to it, but it is difficult to obtain a good electrical joint.

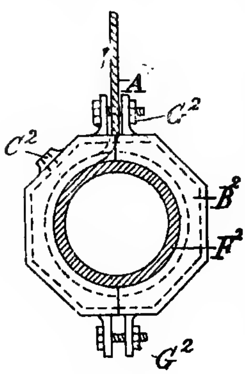


FIG. 22.

The Down Conductors are run to earth. The most important factor in the system is the "earth connection," which is described at page 33; and for greater security it is advisable to inter-connect these conductors, either at a short distance above the ground level or by a buried rod or tape, with each other, and all the rain-water and other pipes, as these having been previously joined together above, will also act as conductors. If the arrangements described have been intelligently carried out the building will be enclosed in a framework of metal, which ought to be sufficient to convey a flash of lightning to the ground without damaging the structure, and at the same

time there will be sufficient points for the discharge of the electricity which gathers on the building during a storm, and these will thus help to neutralise the intensity of the stroke.

To more nearly approach the "cage" mentioned in the L.R.C. Report,* copper would be an expensive material for this system of protection, it also is not so suitable as iron.

IRON CONDUCTORS.

The use of iron as a material instead of copper has been advocated from time to time since the days of Franklin, but it was left to Sir Oliver Lodge to demonstrate the advantages it possesses, and show that a conductor of moderately high resistance, such as iron wire, would get rid of the store of energy contained in a flash in a slower and therefore quieter manner than the ordinary copper tape or cable.†

The material most suited for this purpose is soft galvanised *(or terned)* iron. If made up (with strands of seven ply) about $\frac{3}{8}$-inch diameter, it is large enough for ordinary buildings in positions where it can be easily renewed, but for church towers and other inaccessible places a much larger diameter is preferable. The method

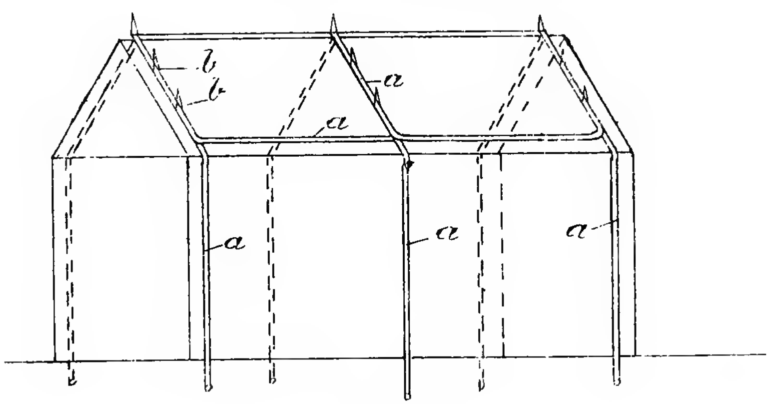


Fig. 23.

of running is similar to that already described, only, having a cheaper material, one can use more of it, and more nearly approach the ideal "bird-cage," of Clerk Maxwell, Fig. 23. *a, a* show the iron wires or rods on roof and sides of the building, *b, b* are the spikes

* See page 7. † See Introduction—Lodge, p. iii.

with which the conductor is armoured; if economy is an object, elevation rods need not be used. In actual practice the number of rods here shown are not required; for instance, in an ordinary building there would be the horizontal conductor on the ridge, with connections to the guttering, the rain-water pipes forming the down conductors. No air terminals are really necessary as the vertical cable may be carried up so as to project above the various chimney stacks, pinnacles or points, and can be opened out so as to present a number of separated wires. The horizontal conductor can be armoured by twisting round it short pieces of steel wire, the two lower legs keeping the conductor a little distance away from the roof.

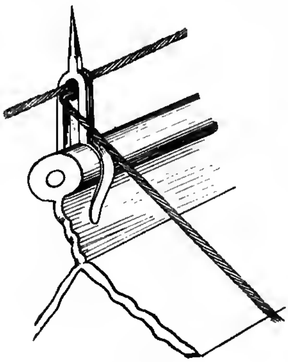


FIG. 24.

The author has designed a special device suitable for use in almost all positions with iron wire, Fig. 24. It is a small triangular malleable iron casting furnished with a spike, when used with a horizontal conductor the two lower legs can be bent to grip the ridge of the roof, or it can be fastened to a lead flat. The same casting without the spike can be used with vertical rods instead of the holdfast, Fig. 12. As shown by Fig. 25, the cable is being held away from a wall.

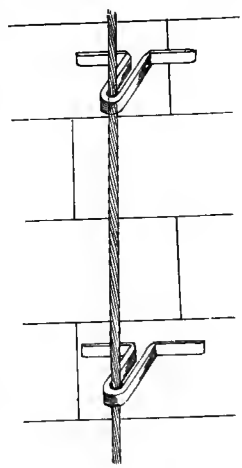


FIG. 25.

A simple and efficient method of joining the *casting* to the cable is accomplished by means of a specially designed ferrule of lead, which is inserted and closed up by a punch; and a somewhat similar joint can be used wherever the system has to be interconnected, and if any particular conductor has to be removed the ferrule can be easily abstracted. In actual practice the wires which form the cage over the building will hardly be noticed from the ground level, the number of barbs on the horizontal wire can be modified; in fact, where there are many pinnacles or chimneys, as each would have its own rod, a few points on the horizontal wire would be all that is necessary. A number of down conductors which may be run with stranded iron wire, as shown by Fig. 24, will descend from the

horizontal rod until they meet the guttering, and if this is not provided all round the building, the gap must be filled with an iron conductor, which can be supported by the same triangular casting. The whole of the pipes in the building should be connected to the system in the manner previously described by means of the guttering at the roof, and again by a solid iron wire near the ground, and as the rain-water pipes are also used as conductors, it is advantageous to bond or inter-connect their joints. There are many ways of doing this; the most practical method would be to have a special lug cast on the socket and spigot, to which connection could be made; however, as the rain-water pipes are often already fixed, the arrangement shown by Fig. 26 can be used. The actual contact is made by lead plugs, which are contained in the two elbows which are pressed against the pipe by means of the clamp.

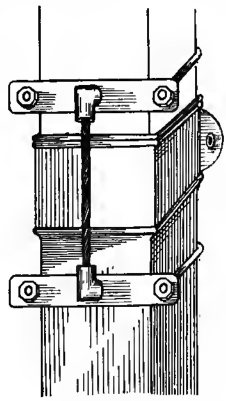


FIG. 26.

Factory Chimneys.—It will be seen by reference to the Reports, Nos. 28 and 57, that chimneys have been struck although fitted with lightning rods. The L.R.C. Rule 4 suggests that "the rods above the band might with advantage be curved into an arch provided with three or four points." This method, which is very general on the Continent, is to be recommended, and the use of iron rods is an economy over the ordinary copper coronal. It is, however, necessary to keep the arch well away from the top of the stack, so that the metal is not over-heated. Fig. 27 gives details of the arrangement in use on the chimney of the Consolidated Engineering Company's works at Slough. It is always advisable to have two down conductors, and if iron is used for these, rod is preferable to stranded wire, especial care being taken with the joints.

The two down conductors should be connected to the coronal on opposite sides of the shaft, and extend from same down opposite sides to a point about 4 feet above the ground line, at which height a similar conductor should be fitted round the shaft, and inter-connected. All metal bands round chimneys should be connected to the conductor. The conductors should be kept away from the brickwork, as L.R.C. Rule 10. Molten zinc should be used for soldering iron conductors; where these are solid the

surface of the joint need not necessarily exceed that of the cross section of the conductors. The joint should be put together previously by screws or rivets, and the soldered joint, especially if used in underground work, should be carefully protected from local electrical action by tarred rope. Stranded iron conductors can be connected (as previously described) by use of a box joint; the box, Fig. 28, must be of the same metal as the conductors.

Vanes.—Particular attention must be paid to the necessity of making a permanent joint to the spindle. A clamp is prepared of the same material as the spindle, and is furnished with two bolts to tighten; if iron is used it is well to line the clamp with a piece of sheet lead. The conductor is sweated into a socket which is fitted with an eye, through which one of the tightening bolts passes. In the

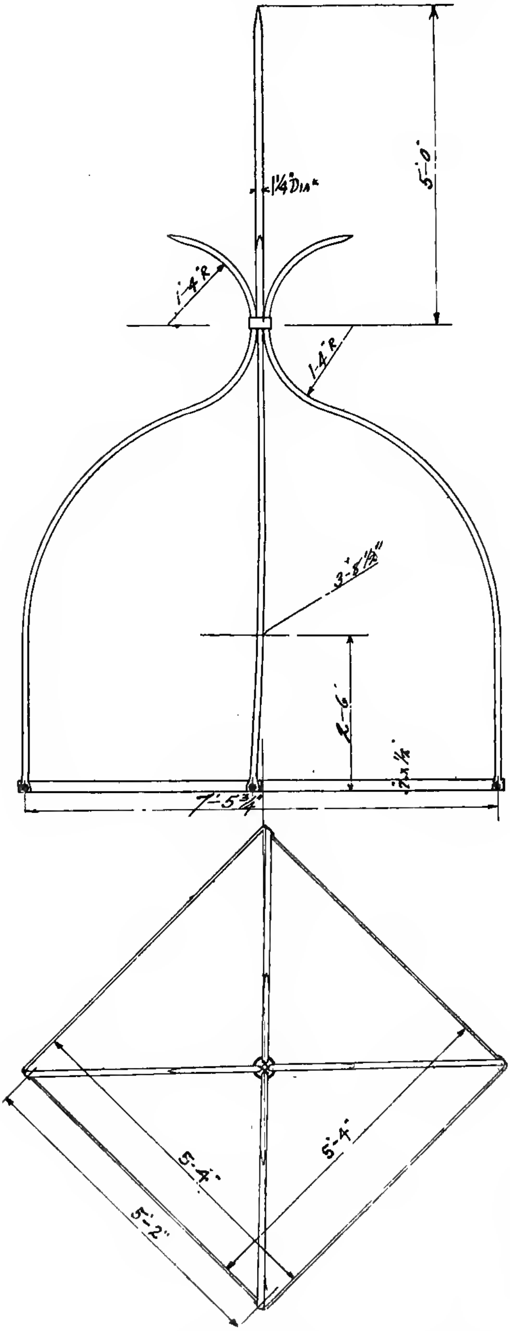


FIG. 27.—TERMINALS IN FORM OF AN ARCH FOR CHIMNEY STACK.

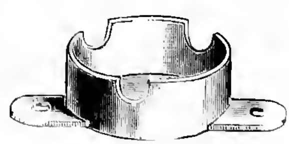


FIG. 28.

case of the vanes of churches and those fixed in inaccessible positions, two separate clamps should be used.

Internal Masses of Metal.—Roof trusses fitted with longitudinal iron tie rods will, as a rule, be found to be electrically connected, but should this not be the case each truss must be joined to the conductors. All large and long masses of metal, such as beams, girders, roof trusses, tie rods, hot water systems, traveller ways, hoisting crabs, engines, boilers, large machines, and ventilators fixed in the interiors of buildings, should be connected to all conductors that pass near them, and as far as possible with one another. The discontinuous parts of traveller rails should be connected by straps, or in some cases tramway bonds might be used. If electric light wires are run in tubes, such as the "SIMPLEX," this should be earthed. Metallic contact between lead or zinc sheeting and flashings should be carefully studied, and for special work strips of sufficient size should be either burnt on to lead or soldered in such a way that the joint will stand rough usage, and allow for expansion or contraction.

Earth Connection.—"*It is essential that the lower extremity of the conductor be buried in permanently damp soil; hence proximity to rain-water pipes, and to drains, is desirable. It is a very good plan to make the conductor bifurcate close below the surface of the ground, and adopt two of the following methods for securing the escape of the lightning into the earth. A strip of copper tape may be led from the bottom of the rod to the nearest gas or water* main—*not merely to a lead pipe—and be soldered to it; or a tape may be soldered to a sheet of copper* 3 *feet by* 3 *feet and* $\frac{1}{16}$ *inch thick, buried in permanently wet earth, and surrounded by cinders or coke; or many yards of the tape may be laid in a trench filled with coke, taking care that the surfaces of copper are, as in the previous cases, not less than* 18 *square feet. Where iron is used for the rod, a galvanised iron plate of similar dimensions should be employed.*

" The use of cinders or coke appears to be questionable owing to the chemical or electrolytic effect on copper or iron. Charcoal or pulverised carbon (such as ends of arc-light rods) is better. **A tubular earth** consisting of a perforated steel spike driven tightly into moist ground and lengthened up to the surface, the conductor reaching to the bottom and being packed with granulated charcoal, gives as much **effective area** as a plate of larger surface, and can easily be kept moist by connecting it to the nearest rain-water pipe. The resistance of a tubular earth on this plan should be very low and practically constant."—*Lightning Research Committee, 1905.*

The methods (printed in italics) here repeated, suggested by the Lightning Rod Conference, still hold good, but great attention must be given to the connection between the conductor and the earth plate; soldering alone is not sufficient, but a mechanical joint is also necessary. Fig. 29 shows a method designed by the author. The arrangement for connecting to water-pipes has already been described at page 26, and illustrated by Fig. 22.

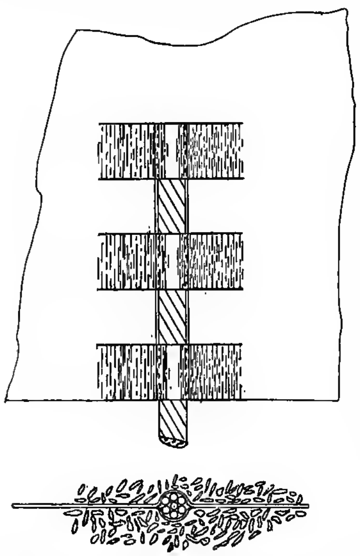


FIG. 29.—PLAN AND SECTION OF EARTH PLATE SHOWING CONNECTION TO COPPER CABLE.

Tubular Earth.—It is well known that the most important matter for attention is the earth connection, and it is misleading, if the present method of burying an earth-plate is employed, to suppose that, even if the conductor has been led into ground which is moist at the time, that after a lapse of years it will still make good electrical connection with the earth, as sometimes the plate is found not to be in electrical contact.

The lightning conductors at St. Paul's were discovered by the author in some instances actually insulated from the earth, although they were not very old, as they had been taken into a conduit which was subsequently drained (Fig. 30). To guard against a recurrence of this danger, which is always possible where earth-plates are buried a few feet under the ground, which may be moist at the time but loses all electrical conductivity by drainage operations, the tubular earth has been substituted, as shown in the following illustration (Fig. 31). This is made in two sizes, and consists of a strong perforated steel pipe, either $1\frac{1}{4}$ inches or 2 inches diameter, and furnished

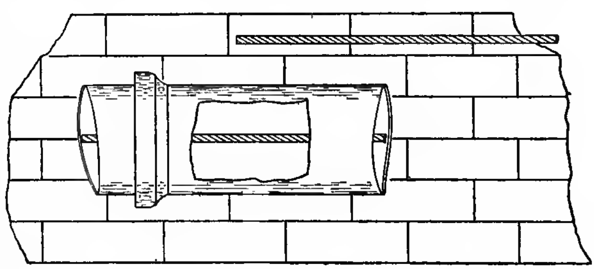


FIG. 30.—SECTION OF OLD CONDUIT, SHOWING EARTHENWARE DRAIN, IN WHICH THE CONDUCTORS WERE FOUND.

with a sharp spike, which will cut its way through chalk or gravel. At St. Paul's Cathedral it was easily driven through the broken stone which marks the site of the previous structure, destroyed by lightning long before Benjamin Franklin's discovery of the lightning rod. The end of the tube having been protected by a thick driving-piece, (Fig 32), which is screwed on temporarily, it is easily sunk by means of a hammer or mallet, and if there is an obstruction the pipe is moved by a bar inserted in the holes of the driving-piece. Lengths, connected by a special form of socket, are added until moist ground is reached. The conductor is threaded through the cast-iron top piece, and dropped to the bottom of the tube, which is filled with finely-granulated charcoal. An electrical joint between the conductor and the cast-iron top is now made by pouring lead or pot-metal into the socket through which the conductor passes, and tamping it in the same way as if it were the joint of a water-pipe. The earth connection is now complete; but, in order to make it permanent, and to keep the moistness which is essential, a small piece of pipe is led from the special hole in the casting either to the nearest rain-water pipe, as shown in Figs. 31 and 33, or, if this is not available, the pipe is allowed to project above the ground, so that water can be occasionally poured down. The cast-iron cap is, last of all, inserted on the top of the tube, and serves to mark the position of the lightning conductor; a useful precaution, as conductors are often cut by workmen who have no idea of their existence. Deep holes near the foundations of a building are avoided with this system of tubular earth; it also has the advantage of being somewhat cheaper than other forms of equipment.

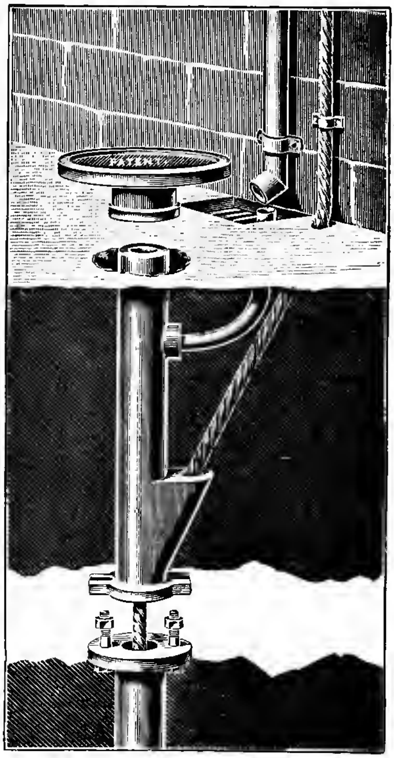


FIG. 31.


FIG. 32.

The number of earths depends on the ground area of the building; there cannot be too many, and it is advisable to divide them up as much as possible. For instance, at St. Paul's Cathedral, Fig. 34, although the connection to the water main on one side and to the Hydraulic Power Company's pipes on the other gave almost perfect earths, others, both of tube and plate form, were sunk at the various points marked by the **O**. The network of conductors on the roofs is also shown, the position of the aigrettes being marked by the small **o**.

TESTING.

This may be considered under two heads:—

A, the Conductor itself,

B, the Earth Connection.

If the main conductors are made of continuous lengths of stranded wire or tape, joints need only occur where the horizontal conductors meet the main conductors, and this should not be if possible in inaccessible places, anyhow the joints should be good mechanically as well as electrically, so that they will last as long as the conductors.

A.—The electrical testing of the whole circuit becomes more difficult as we approach the cage formation. A careful visual inspection will show if any joints are loose or parts displaced, and it is quite possible to insert test clamps so that a portion of the system can be isolated, but these without they are inspected from time to time may give trouble.

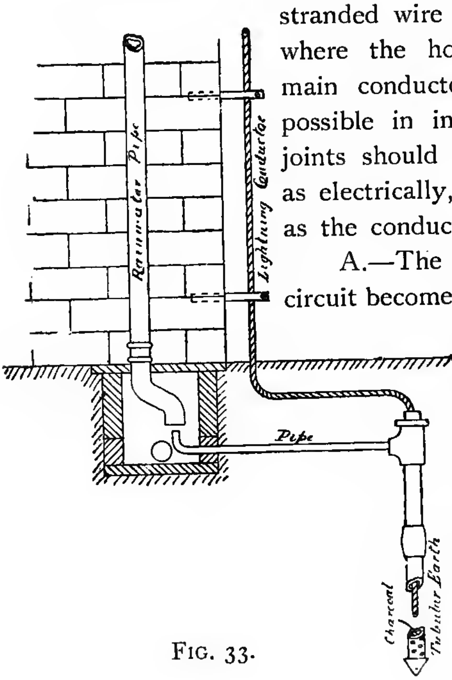


FIG. 33.

B.—The earth connection can easily be tested by providing a test clamp in some place near the ground, where it cannot be interfered with, and where earth plates are used it is advisable to examine and test them annually. With the tubular earth this is unnecessary, a blow with a mallet will show if the tube has become loose in the ground, and as long as the contact is good, the electrical

resistance will be unaltered, providing always that there is sufficient charcoal to fill the tube and that it is kept moist. In very dry weather or in countries where no rainfall takes place for a considerable time

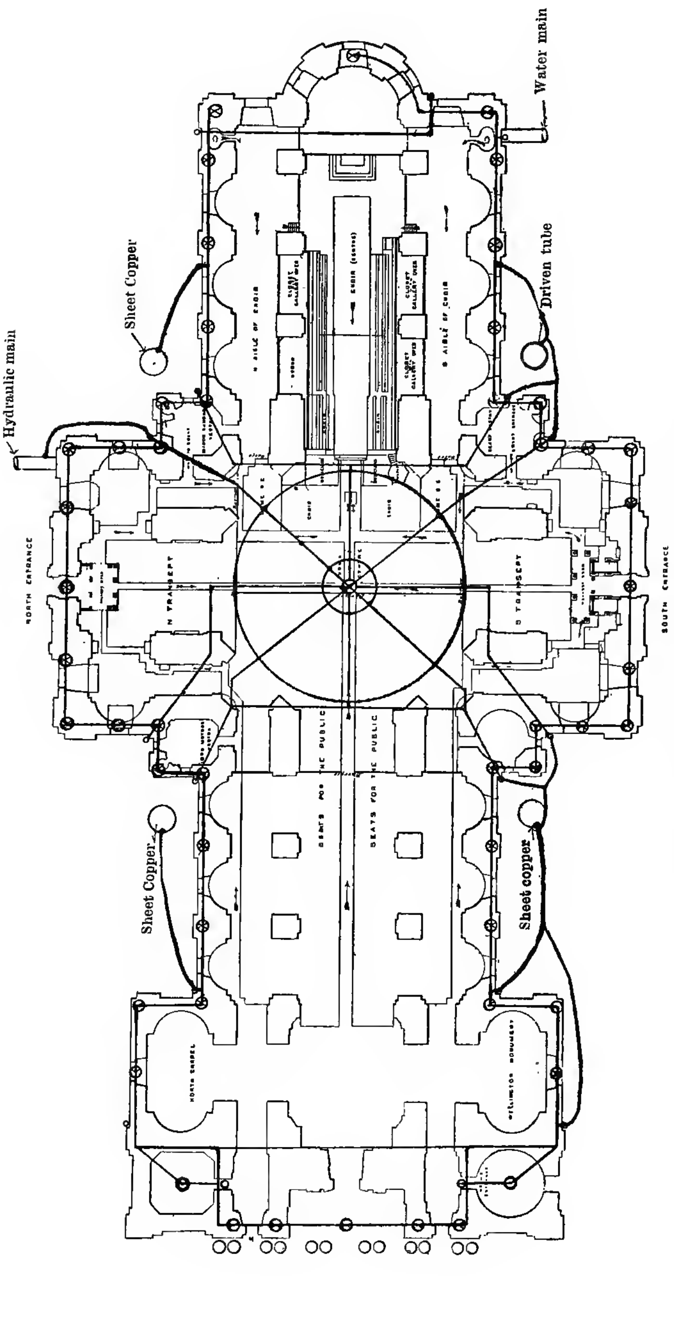


FIG. 34.—PLAN SHOWING THE LIGHTNING CONDUCTOR INSTALLATION AT ST. PAUL'S.

water should be poured down the tube by a pipe, which can be attached in any convenient position.

Elaborate testing is unnecessary, but occasional testing in ordinary weather is no real security as to what may happen after a long continued drought. Sir Oliver Lodge suggests the following simple plan:—

"Two earths should be provided quite independent of each other (one a water main for instance, the other a ton of coke), and they should be connected first to each other, and then to the conductor by a copper band. Now let the band connecting the two earths pass through some covered out-house, and have a well overlapping junction of two flat areas pressed together by a spring, but capable of being raised on or off each other by pulling at a handle or a rope. A Galvanometer indicator and Leclanchè cell permanently connected so as to send a current between the two earths directly the handle is raised, will show by its deflection the state of conductivity of the two earths. The Galvanometer and Wheatstone Bridge and Ohm's law and conductivity are simply not in it, and can no more point out what path lightning will take than a trickle down a hill-side will fix the path of an avalanche."

The Admiralty suggest the case of an ammeter with divisions, each of which represents 0·02 ampères; two accumulator cells connected in series are joined through the instrument to the two earth connections under test, the current being sent first in one direction and then in the opposite. If the observed steady current is 2 ampères or more then the earth is in good condition.

Examination of a Building after a Lightning Stroke.—It is not a very easy matter to definitely fix the course of a flash, especially if the damage is slight. A careful observer will trace out its path by signs on the brickwork, and often by pieces having been chipped out of rain-water leads and sockets of pipes. A faulty earth is easily recognised by the upheaval of the ground where the conductor enters. The author has found some of the external metallic work partially magnetised after a building has been struck, and it would be very interesting if a number of observations were made.

The Lightning Research Committee issued the following to their observers to aid them in making their reports:—

"1. Any signs or indications of where the flash appears to have first struck, and an account of the damage done.

"2. A specification and drawing of the metal-work of the building, paying special attention to metal of every kind which comes anywhere in the

neighbourhood of the conductor, whether roof guttering, lead covering, rain-water spouts, sewer ventilators, telephone wires, bell-wires, gas-pipes, ornamental railings, &c., &c., carefully ascertaining whether any of these were either purposely or accidentally connected with the lightning conductor, and, if not, what their nearest distance was from it.

"In the drawing, all metals may be indicated in *red*, no matter of what kind they may be; the hypothetical path of the lightning, as appears to the observer most probable, may be sketched in *blue*, remembering that bifurcation of path is not unlikely. Places of damage may be indicated by a blue swelling or patch, the size of the patch giving a rough idea of the relative damage, and an arrow being employed, when necessary, to call attention to any small patches liable to be overlooked. The patches may be numbered, and the nature of the damage at each place stated in the description. Any place where fire broke out is to be specially attended to.

"3. The nature and condition of the conductor, especially with reference to its continuity, its earth, and its elevation; also how fixed, and, if carried horizontally, its length as compared with the vertical height of its terminal above the ground; also note whether it made any sharp curves or loops round projections of the building, or took an indirect course. Cases of damage where there have been more than one or several conductors are specially important.

"In the case of church steeples the wind vane should receive special attention, and the mode in which its rod terminates in the steeple should be ascertained.

"In the case of chimneys, any internal metal flue should be carefully specified. Likewise any indication that the flash took the column of hot air in preference to the conductor should be recorded; also whether the conductor was bent or curved over the mouth of the chimney or not.

"In any case of importance the earth of the conductor should be specially examined, being, if possible, dug down to for this purpose; and a complete specification of the nature of the earth, the nature of the soil, and of any metal ramifications as well as of moisture in its neighbourhood, should be made.

"Any signs that the discharge has entered the earth should be recorded; and if the conductor is at any point damaged or otherwise affected, this should be specified, and, when interesting, a sample of the damaged portion should be sent. If the conductor has recently been examined and tested, or otherwise reported on, the fact should be stated."

CHAPTER V.

CONSIDERATIONS AS TO COST AND SPECIFICATIONS.

THE following extract from Sir Oliver Lodge's preface* to the Lightning Research Committee's Report, aptly defines this question. "The amount of protection to be allotted to any building is no doubt analagous to the question of insurance generally; that is to say, the amount of premium it is desired to pay may be compared with capital at stake and the risk run; and this is doubtless a matter for individuals and public bodies to consider for themselves."

The author's conclusion is that there is very little advantage in what might be termed "unit lightning rods." For instance, in London one sees isolated rods on certain of the chimney stacks of the many Board Schools, it is true that if these particular chimneys were struck, the damage to the building would be greatly lessened, but why should they be selected, while the metal work about the roof, also the other stacks, are left unprotected?

If a building has a high tower—or a church, take for instance, with a spire—it would be extremely foolish not to provide one or two conductors running from the highest point to earth; but this gives no security to the nave, and if any other part of the structure happens to be in the path of a discharge from a cloud to the ground the stroke may disregard the protected tower or spire and fall on the building, choosing some lower point.

The question then is not the erection of a rod or rods, but of the amount of money to be spent on the entire system. Usually the question of the maintenance of a building is of sufficient importance that it is proposed to spend annually a certain sum of money to keep it in good repair; this amount would be increased by so little to keep a well designed system of lightning conductors in order that the

* See Page iii.

amount is hardly worth consideration, so that the only point to examine is that of first cost.

Storms are dissipated by the smoke from a collection of chimneys such as are found in large towns, and the numerous overhead wires have doubtless a shielding effect; it is therefore not so necessary to fix lightning conductors on buildings in cities as on those in the suburbs, which are more liable to be struck. All prominent buildings, such as churches, banks, and any having a high dome or tower, should be protected wherever they are. This remark especially applies to public buildings and to museums, art galleries, hospitals, prisons, government and municipal offices. It seems anomalous that large sums of money should be spent on the protection from fire of our national collections of art treasures, while the question of possible damage by lightning is simply ignored.

All flagstaffs should have a conductor with a point fixed above the cap and run directly to earth, also a connection to all the metallic supports of the rod.

Note that certain localities are especially in the path of storms, and that a building once struck is liable to be again damaged, so that special care should be taken in protecting it. Farm houses and barns and windmills are frequently struck, also small residential buildings which are so numerous in the outskirts of towns. The question of expense deters many owners from considering the matter, but by using iron wire, a rough-and-ready system of lightning rods could be easily installed which would be quite as effective as the present costly arrangements.

STEEL FRAME BUILDINGS.

"No cases of damage to modern steel frame structures have come under the notice of the Committee. The ordinary method of construction, however, in this country does not provide full protection. In many cases the steel columns stand on stone foundations, and the metal is not carried deep enough for effective earthing. The metal columns ought to be earthed at the time of construction." *Extract from the L.R.C. Report.*

The American system of construction provides in itself the "cage protection" which has been described, and if care is taken to join up electrically the metal work of the roof with the frame, and also see that this is well connected to earth, not in one or two places

only, but in such a manner that a flash may be quickly dissipated no supplementry conductors are required.

Fig. 35 is taken from a photograph of a building under construction. The author recommended the placing of aigrettes (Fig. 8) at intervals on the roofs, and joining these by cable conductors to

FIG. 35.

the metal principals below, iron rods were also fixed to the columns above the concrete foundations and inter-connected with earths sunk into moist ground.

SPECIFICATIONS IN DETAIL.

The following are from actual Specifications by the Author for various kinds of buildings.

NO. 1.—MODIFIED CAGE PROTECTION, COPPER AND IRON CABLE.

Fig. 36 shows the new building of the Royal Horticultural Society, Westminster, E. Stubbs, R.I.B.A., Architect. It consists of a front as shown, also a large hall at the back, with an arched roof, mainly glazed, supported by iron girders; the roof is carried partly by the brick walls and partly by iron columns. The whole of the rain-water pipes are part of the system, as well as the special conductors. The tubular earths on the front side are shown.

Rochester Street Side.

One conductor of seven $\frac{1}{8}$-inch strands galvanised iron wire, will run along, as shown in plan, near spring of arches on two sides of the hall, starting from two of the iron uprights nearest the earths, this conductor will, at four places, descend to earth close to the discharge

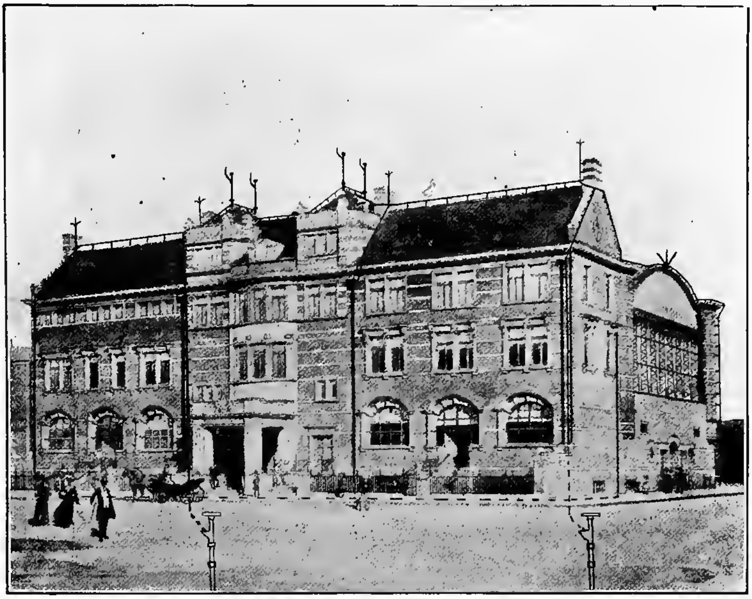


Fig. 36.

of the rain-water pipes. The conductor running horizontally will be connected to the base of each of the vertical girders by being fastened to them with galvanised iron cleats, which will be secured by two $\frac{3}{8}$-inch screws. The cable will therefore be inter-connected to all the metal work before running to the two earths at each side of the hall.

At the top of roof provide and fix three 4-point copper standard pattern aigrettes, Fig. 11. Connect each to ridge of ironwork by two $\frac{1}{2}$-inch galvanised iron screws, a piece of lead being placed under the iron base of each casting, and lead washers under heads of screws, which must be a tight fit to prevent water getting into the screw holes of the casting.

Frontage to Vincent Square.

A $\frac{3}{8}$-inch 7-ply stranded copper conductor should be run along the ridge of the roof, being kept away about 3 inches from same and held by a form of holdfasts, which are fitted with specially designed

pieces of flat copper of ∩-shape, so that they can be sprung round the ridge tiles. This conductor will be taken up the four chimney stacks, being kept away from the brick work by holdfasts (Fig. 12), and will be connected at each chimney, by a box joint, to a ½-inch solid copper air terminal fitted with three points; the conductor will also be joined by means of box joints (Fig. 28), without cutting same, to branches leading up the two gables, and by continuing same to top of the four lead-case flèches, and with single point elevation rods on the top of these. This conductor will be connected at the back to two of the earths which serve for the opposite side of the roof. Care will have to be taken when making these connections of copper cable to iron by means of box joints, that no galvanic action is set up, and the boxes should be of galvanised cast iron, the galvanised conductor being connected to the outside of the box, whilst the copper is sweated, by molten pot metal, to the inside of the box. In the front the two down conductors will descend by the roof to earth as shown—always kept away from the wall by holdfasts—then down the front in a position where they will be least noticed, until they arrive near, but not touching, the rain-water down pipes; they will then be led from the front wall underground to two tubular earths, which will be automatically kept moist as described. These earths will be connected to the bottom of the rain-water pipes, and similarly all guttering and rain-water pipes will be connected to the conductors, the latter at the rain-water heads. All the ventilating and other pipes will be connected to the system near the gutters and inter-connected about 2 feet from the ground by a galvanised iron wire.

EARTHS.

These, six in number, will be on the tubular system, and each consists of a 1¼-inches wrot iron tube, furnished at its lower end with a perforated steel point.* This tube will be driven absolutely vertically at least 8 feet below the lowest excavation, if any, or the lowest foundation of the building. If the ground is soft the tube must be sunk until it hardly moves with a full blow of a sledge hammer. At surface level an extension piece of cast iron is attached, fitted with a movable cap, on which is cast "Lightning Conductor," which is to be flush with the ground. The cable in each case runs into a socket of this cast-iron piece, and then to bottom of the tube, which is filled with

* Instructions for driving, and for removing an obstacle if met with, are sent out by the patentees' licensed makers.

granulated carbon and gently rammed. Electrical connection is made between the cable in the socket by pouring in lead, which is tamped, so that the cable is held firmly in the centre of the socket. A piece of $\frac{1}{2}$-inch gas pipe is inserted in the cast-iron piece, and led to the nearest rain-water pipe, so that it looks up the inside of same; it is covered with a small cap of woven wire to exclude dirt.

CONDITIONS OF TENDER.

The Contractors to supply the whole of the materials required, and execute the work to the entire satisfaction of the Consulting Engineer. The Contractors to supply all ladders, scaffold, or any tools necessary for the work, and to be solely responsible for any compensation to workmen under the Employers' Liability Act. All materials to be submitted to the Consulting Engineer before erection, and, if so required, an electrical test to be made in his presence.

A ground plan, on which the position of conductors and of earths is shown, accompanies this Specification.

NO. 2.—SPECIFICATION FOR THE PROTECTION OF A CHURCH—COPPER CONDUCTORS.

A building of ordinary design, with spire of masonry, on a tower; the nave and lower part forming the chancel have slate roofs.

THE SPIRE AND TOWER.—The vane spindle is connected by means of a band of same material, shaped so as to spring on and make a good fit. If of copper, the band may be strip, $1\frac{3}{4}$ inches by $\frac{1}{8}$ inch, secured by one $\frac{1}{2}$-inch and one $\frac{5}{8}$-inch copper bolts and nuts, the conductor to be, if only one is used, of seven strands, $\frac{3}{4}$-inch outside diameter cable (if two conductors are run down opposite sides of the spire each can be $\frac{1}{2}$-inch diameter), to be fixed to the band by a strong copper socket, which is to be sweated to the cable, and also secured by two set screws, the eye at the other end of the socket to be firmly held by the $\frac{5}{8}$-inch bolt, the band being formed to receive the flat end of the socket. The cable will be kept at intervals, say, of 10 feet, away from the stone work by holdfasts (Fig. 12); if there is a rain-water pipe near the base the cable should run to earth near this pipe, and the conductors must be kept clear of the coping by a holdfast on the tower, and be led at a very wide angle to clear same; a subsidiary cable, say, of seven strands, $\frac{3}{8}$-inch diameter, should be connected to any metal work or flashings on the tower, and if there are pinnacles, this should go right round outside, and a solid copper

¼-inch diameter rod be run so as to project, say, 6 inches, clear above each pinnacle, and be jointed to the cable by a box joint without cutting. See page 24.

THE NAVE.—A horizontal ½-inch cable will be run on holdfasts, at least 3 inches clear of the ridge, joined to the conductor descending from the tower (the number of holdfasts to be sufficient to prevent sagging); the cable on ridge will descend at the extreme end (first over the chancel, if it is lower) to earth; at intervals, say, between alternate windows, ⅜-inch stranded down conductors will be led down slope of roof over guttering to earth on each side (this cable can be stopped at the rain-water heads if expense is an object), it is to be connected, if passing close to rain-water heads, by cutting a strand and sweating the two ends to a socket and eye-bolt as previously described, and if the distance exceeds one foot, then a piece of ¼-inch copper wire must be used. It is similarly to be connected to the guttering, which must also be in contact with the rain-water heads.

NOTE.—The joints of rain-water pipes should be bonded, especially if of loose fit, or filled in with an insulating cement.

On arriving at lowest point, if this is in a dry area, run a ¼-inch solid copper wire on gun-metal eyes right round the building, about 2 feet from ground, and connect this to all the down conductors, water pipes (not gas pipes), and other pipes or metal flues of every description, by means of box joints, or by carefully twisting several turns of ⅛-inch copper wire and soldering at each connection.

Another method is to bury the ¼-inch solid copper and similarly connect—in which case a notice should be put on the walls to avoid accidental interference.

Earths.—The number of these will depend on the ground area of the building, but should never be less than four; the down copper cables must be run to the earths in as direct a manner as possible without joints. If plate earths are used the cable must be mechanically fixed (see Fig. 29) and sweated. With this description of earth a disconnecting clamp for testing (of approved pattern) should be provided at or near the wall, at such a height that it cannot be interfered with.

With tubular earths that are kept moist automatically these clamps are not of importance.

PLATE earths should be dug up after they have been fixed about a year, to see that the copper is in good contact with the charcoal; tubular earths can have a little more of the material

inserted from time to time if on removal of the cap it is not visible in the cast-iron extension piece.

Aigrettes (see page 22) should be fixed on the horizontal conductors at distances of about 30 feet apart, all crosses, points or finials of every description should have a single point conductor, and any stove pipes should be connected above and below to the upper and lower conductors.

NOTE.—The motion work and movement of clocks should be connected to the system, also the framework of the bells, should this be metallic.

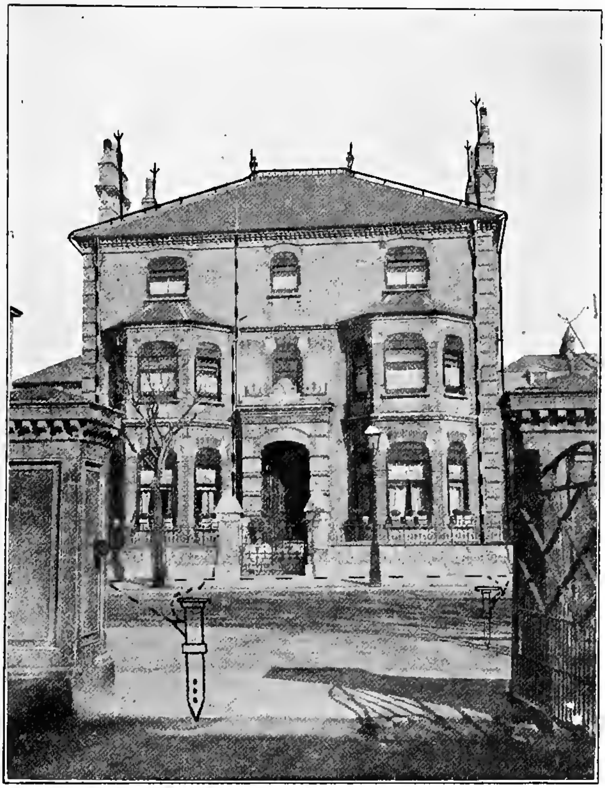


FIG. 37.

If the spire is covered with metal, at least two separate conductors should descend to earth; and in this case they may be laid in contact with the sheathing, and be fastened by straps instead of holdfasts. Iron staircases or hand-rails in towers should be connected at top and bottom to the conductor, also all lead roofs and flashings, iron framework of windows and stove.

The rules of the L.R.C. should be embodied in the Specification.

NO. 3.—IRON CONDUCTORS.

The following is a Specification of the conductors on a detached residence at Hove. Fig. 37. A horizontal $\frac{3}{8}$-inch diameter cable of 7 strands iron wire is run across the ridge, but kept away by special

holdfasts, to which it is secured, and rests on the top of the iron cresting; at each chimney stack a similar cable rises to 1 foot above the pots, and is opened out to form spikes, the joints being made by a lead ferrule, as shown in Fig. 24; the conductors descend to ground on two sides of the house, being held away from the walls by holdfasts, Fig. 25. On the roof it connects on two sides to the gutters, and at the points shown by the finials on the cresting four similar conductors descend the roof, and are also connected to the gutters. The gutters are connected to the rain-water heads by special clamps, care to be taken to prevent electrical action at the joints. The ventilating pipes are also connected to the system, and in the area a No. 10 gauge galvanised iron wire is run all round the structure through eyes which are driven into the wall; this wire passes round all pipes and is soldered to the two $\frac{3}{8}$-inch cable lightning rods. The bottom of all the rain-water pipes is also joined by cable to the conductors, as shown. The "SIMPLEX" tubes containing the electric light wires are to be earthed, also the gas service, as L.R.C. Suggestion 8.

EARTHS.—These are of the tubular form, and are two in number, fixed as described at page 33. The cost of all the work, exclusive of the two earths, one on each side of the house, was about £10.

FARM BUILDINGS.

A general idea of what is necessary can be obtained from the foregoing description, but should there be no guttering, it would be necessary to run a small cable, or even a solid wire, round the eaves, and connect the horizontal conductor to this by similar cables or wires down the roofs. Good earth may often be attained by leading the conductors into a brook or well, but several yards should be coiled up in the latter case or spread along the bed of the stream in the former.

NOTE.—Copper should not be placed in any well or small stream used for drinking purposes.

A more complete protection would be arrived at by more closely imitating the cage shown by Fig. 23, that is, the building would be enclosed by a greater number of horizontal and vertical iron wires. In the case of factories where inflammable materials are used, such as celluloid, or where fireworks are manufactured, the extra expense would be justified by the greater security.

MAGAZINES USED FOR EXPLOSIVES.

The L.R.C. in their Report, page 413, say:—

"For structures intended for the manufacture or storage of gunpowder or other explosives the adoption of the bird-cage protection would be justified alone on the score of public safety. The method of erecting single lightning rods would not afford sufficient protection."

The way to make such a building perfectly safe is to completely enclose it in iron, the floors may be lined with wood or other soft material to prevent ignition of stray powder by persons walking on the iron. Such a building, according to Lord Kelvin, "would be perfectly safe, the need for the earth is absolutely done away with if the magazine is completely enclosed in metal." These views are confirmed by the report of H. M. Inspectors of explosives for the year 1900, who comment on the two accidents in the factories of the Nobel Explosives Company at Krummel and Hamm, Germany.

CHAPTER VI.

NOTES ON AMERICAN AND CONTINENTAL PRACTICE.

THE "lightning-rod man" is well known to all settlers out West, and his pertinacity in introducing business has made the profession a synonym for "smartness." As a rule the protection afforded by the travelling expert is very small, and when the author was engaged in railway engineering in the United States he often found that the two iron rods fixed to the sides of a farmhouse had a very indifferent earth connection and were simply driven a short distance into the ground. A better method is now often adopted, a round iron rod about $\frac{1}{2}$ inch in diameter extends from the ridge of the metal roof about 4 feet above the top of each of the chimney stacks, its lower end being connected to a piece of iron in the form of a saddle which is soldered to the metal roof, to this also is joined the top of each rain pipe by means of the guttering. The rain-water pipes are connected by an iron strap to the earth, which is made by driving a pipe into the ground until it reaches moist earth; the upper end of the pipe is left about 6 inches below the surface, thus it can be watered artificially or by the rain. To assist the collection of moisture, a larger sleeve is sometimes placed outside furnished with a perforated top and set flush with the gutter. With slate or wooden roofs, it is recommended that bands of tin plate or galvanised iron are inserted under the slate covering on the rafters of the roof, being connected at the top with the "air terminal" conductors, and below with the gutters and rain-water pipes as previously described; in the case of a mansard roof the sheet metal or flashing is also connected to the system. It is stated that if all the connections are properly made, so as to secure good electrical connection between themselves, the rain-water pipes, and the earth, there is no liability whatever of the woodwork or other material about the roof being set on fire or damaged, or any person beneath the roof being injured by the electricity in a

lightning discharge while passing through the combination on its way to earth.

In a more recent visit it was found that greater attention had been paid to the question of protection, a special form, somewhat similar to that used by the L.R.C., having been prepared by the Weather Bureau of the United States Department of Agriculture and largely circulated.

During the year 1898 reports were received from 1,866 cases of buildings being damaged or destroyed, directly or indirectly, by lightning, the damage to buildings and their contents being $1,441,880, but only a small proportion of these were fitted with lightning rods. There was an immense amount of damage to live stock. In one State, Iowa, 266 head were killed in 1898, and of these 118 were found in close contact with wire fences, which were not protected by ground wires. The report stated: "Unquestionably, wire fences as now constructed serve as death traps, causing a vast amount of loss every year; there were evidences that the lightning struck the fence at a considerable distance from the point where the stock was killed."

A large number of people are struck by lightning every year while either hanging or removing clothes from the wire ropes, which are much used instead of the ordinary clothes line.

In 1902, the opinion seems to be gaining ground that the methods adopted in the past required improvement, and that owing to the very inefficient protection which had been afforded by the contractors who had installed lightning rods on many public and private buildings, lightning rods were dropping out of architects' specifications, so that few new buildings were protected at all; they were often struck, but as the insurance policy covered the loss, little notice was taken, although deaths occurred either by direct stroke or from chimneys or masonry falling. The author was informed that the then present conditions were thought to be unsatisfactory, and that architects and engineers generally would like to be advised as to what protection they should adopt. That large amount of damage by fire caused by lightning did take place, was shown by the reports of the Fire Commissioners of many cities. The action of lightning when striking those high steel buildings known as sky-scrapers is peculiar, and is worth investigation, as examination does not show in what direction the current flows to earth. In many cases in New York the buildings are insulated from the ground by the fact that the foundations are blasted

out of the rock on which the city is built; however, they appear to be lightning-proof. The subject is further considered in the report of the stroke at Boston which is illustrated and described at page 82.

Latest Practice Abroad.

GERMANY.

Much attention to the subject of a better method of protection has been given. In 1901 a sub-committee of the Berlin Elektro-Technical Association was formed, consisting of Messrs. Aron, Feussner, Findeisen, Naglo, Neesen, Nippoldt, Strecker and Leonard Weber. The following is an extract of their recommendations:—

"1. The lightning receivers should consist of vertical points. The points of towers or gables, edges of the ridge of the roof, tops of chimney stacks, and other high parts of buildings, should be converted into receivers, or be provided with suitable receivers. The conductors should be in metallic connection with the receivers and the earth; they should go round the building, the roof especially, and if possible on all sides, and then be led from the receivers to the ground by the most direct route, avoiding as much as possible all sharp curves. The earth connections should consist of metallic conductors connected to the lower conductors on the building, and should descend into the ground and extend as far as possible, preferably where the earth is damp.

"2. The metallic parts of the building, and masses of metal in and upon it—especially those in contact with the earth and offering large surfaces (such as pipes)—should be connected together as much as possible, and to the conductor also. Special receivers and conductors are rendered unnecessary if these metallic parts of the building comply with the requirements mentioned in paragraphs 1, 4, and 5. Both for perfecting the system and for decreasing cost, the question of utilising the pipes as conductors should be considered when erecting new buildings, making use also as much as possible of all the metallic parts of the building for protective purposes.

"3. The protection afforded by a conductor is the greater the more perfectly all the prominent portions of the building are protected by receivers, the larger the number of receivers and conductors, and the more extended the connections to earth. Generally speaking, damage by lightning is diminished if all the metallic parts of buildings of considerable extent are inter-connected, especially if the highest parts are connected to earth, even if these connections are not made specially with a view to protection from lightning.

"4. Inter-connected conductors of iron should not have a section of less than 50 square millimetres, unconnected ones not less than 100 square

millimetres. If of copper, half the section is sufficient; zinc must be one and a half, and lead three times the section for iron. Conductors must be securely fixed to resist strong winds.

"5. The connections of and to the conductors must be made strong, be of good electrical contact, and with as large a surface as possible. Unwelded and unsoldered connections should have metallic surfaces of contact of not less than 10 square centimetres.

"6. The lightning conductor system should be repeatedly tested; and when alterations are made in the building, the necessity of alterations in the system of lightning conductors should be considered."

Baurat Findeisen, of Stuttgart, deduces from certain statistics as to strokes by lightning in Würtemberg that there is some doubt as to the efficacy of intercepting rods in attracting and protecting against lightning, and that there is no point in measuring the resistance of lightning conductors, since the high pressure of lightning would overcome even high degrees of resistance. It would be sufficient, he thinks, if all the protecting sheet metal on the roof-ridge and elsewhere were connected with the gutters and rain-water pipes—if the chimney, which is so often struck, were protected by a rope of galvanised iron wire, projecting to a height of one-half to one metre above the chimney, and joined as conductor with the protecting metal, and if the water pipes were used as earth connections, they also having a strong wire rope running along them, which, at the lower end, should be untwisted and carried in fan shape about half a metre down into the ground. Four such earth connections at the corners of the building to be protected would, he considers, suffice. If yet further precautions are desired, galvanised sheet iron might be substituted for this. Lightning conductors of this type, Herr Findeisen states, have proved their efficiency.

In his book entitled "Rathschläge u.d. Blitzschutz" (Berlin Springer), he describes very cheap methods of protection. On page 229 he states:—

"The main point is to guard against fire; it is of more importance to reduce the £200,000 which Germany loses every year through lightning to a minimum by simple precautions, than to bring it down to nothing in individual cases by a disproportionally large expenditure."

He evidently prefers more elaborate installations, as the conductors now being fitted to the new Town Hall at Stuttgart in accordance with his specification are to cost not less than £200, a sum not much less than the £250 expended on the protection of the Hotel de Ville at Brussels.

German practice has been for a long time in advance of what we have been accustomed to here. The rules referred to are only the elaboration of a system which has almost universally been adopted for the protection of public buildings in Germany. For instance, at Cologne Cathedral the work is very carefully executed, and of a design which might be followed with safety. Stranded copper cables are used, and these invariably run through galvanised iron stanchions with flat feet, by which they are bolted to the stonework. To avoid galvanic action setting up between the iron and copper, the eyes of these supports are bushed with lead. They keep the conductor about 7 inches away from the structure, or sufficient to enable the cable to be stretched tight and not run round projections in the manner we are accustomed to see here. For this purpose there are tightening screws at several points. A somewhat similar arrangement is used for the horizontal conductors which run each side of the roof, being kept well away from it. The terminals of the lightning rods are almost always plain spikes without branches, but a building has many of these, both on the highest portions and along either the tops of the walls or ridge of roof, the whole being connected together by the horizontal conductor, which is usually run in the method described. A timber shed near Frankfort has these vertical rods about 15 feet apart, and a circular petroleum storage tank at intervals all round the top.

Many local boards in Prussia insist upon lightning conductors being fitted on public buildings, such as schools, town halls, hospitals, and churches. The regulations vary with the different local authorities. In Frankfort the Municipality have the following: "The erection, alteration, and repairs of lightning conductors must be in accordance with the scientific rules now in force. The conductors must be of pure copper, and of not more than seven strands. House owners must have their lightning conductors examined at least every two years, and an examination is also required in the case of the erection of, or alterations or repairs to, a lightning conductor which has been struck. Designs and specifications of proposed erections must be submitted to the local board, and for the accuracy of the same the house owner is responsible."

HOLLAND.

The following is translated from the Dutch of the very complete and valuable report made by Dr. D. van Gulik at the request of the Dutch Academy of Science, which has recently been published under

the title of "Further Inquiries in regard to the Protection of Buildings from Lightning" (Haarlem, 1905):—

"1. Lightning conductors serve to lessen the *risk of fire* and of serious damage for the buildings protected by them, and to reduce considerably the *danger to life* for those who inhabit the buildings. Whether the *risk of a building being struck by lightning* is also lessened by the installation of points or bundles of points is very doubtful. Where, therefore, economy is an object these may be first dispensed with.

"2. In protecting buildings from lightning we must bear in mind that, contrary to what we notice in the case of constant electric currents—

"(*a*) Lightning shows a great tendency to distribute itself over such conductors as may be present, and in so doing pays little heed to the electrical resistance of the conductor.

"(*b*) That it finds no great difficulty in making its way, often for a considerable distance, through the air or through any other good conducting medium.

"(*c*) That it prefers to move, as far as possible, in a straight line, and that, therefore, sharp turns or spiral windings in conductors present hindrances which, in view of the properties mentioned in paragraphs (*a*) and (*b*), readily lead to lateral discharges.

"Absolute security is not attainable, or attainable only with great difficulty, and in any case at considerable expense. On the other hand a quite satisfactory degree of protection can be secured by very simple means.

"3. The greater the importance attached to the preservation of a building and its contents, the more perfect can the system of conductors be made, and thus a higher coefficient of safety is obtained by increased expenditure.

"4. The conductors at present used in Holland secure a fairly high degree of safety in the case of houses with tiled or slated roofs, as they reduce the risk of fire when struck to an average of between one-sixth or one-seventh. Statistics show, however, that the lightning frequently diverges from them, and may even strike the buildings without touching the terminal rods. Moreover, the cost of installation is so great that many people are deterred thereby from having these useful appliances fitted. Certain general improvements and simplifications may, however, be pointed out, by means of which the conductors would, even at a lower cost, better answer the purpose for which they are intended.

"5. The *improvements* are in the main as follows:—

"(*a*) All salient positions liable to be struck should be provided with terminals in the form of short rods or wires, and the roof should be girt round on all sides by wire conductors. This would take the place of the high terminal rods with their imaginary cone of safety.

"(*b*) Several conductors running to the earth should be fitted.

"(*c*) The system of conductors should be connected with any extensive metallic mass present in the building, if necessary at more points than one. In the case of gas and water pipes such connection is absolutely necessary.

"6. The principal *simplifications* may be summed up thus :—

"(*a*) High terminal rods should be abolished, as it is difficult to fix them firmly enough.

"(*b*) Copper, which is the material generally used for conductors and earth connections, should be replaced by iron. This, if well galvanised, will resist atmospheric influences for a very long time, and can, moreover, be easily protected by a coat of paint.

"(*c*) The thickness of the conductors should be reduced. In support of this we may adduce the evidence of the ordinary telegraph wire, which is seldom, if ever, found to be melted except at the point where it is struck. Even in providing for extreme cases we should not lose sight of the fact that a wire will do its duty even though it succumbs to the force of the stroke.

"(*d*) The metallic constructional portions of the building should be pressed into service as conductors. By this means either the conducting system is extended, with a consequent increase in the margin of safety, or the use of special conductors may be partly dispensed with. This last expedient provides a ready means, in the case of special classes of buildings, of providing quite efficient conductors at a trifling cost. It is not necessary that there should be metallic contact between the metal constructions provided that they overlap one another over an area of 10 square centimetres.

"7. In making earth-connections too much importance is often attached to reaching the ground water level, while on the other hand too little care is taken to secure a good connection between the conductor and the uppermost layer of soil. By paying attention to this a considerable saving may in some cases be made in the cost of the earth-contact. In isolated cases where connection with underground pipes, &c., is possible, no special earth connection is necessary.

"8. When building houses it is desirable that the conductors should always be marked on the plans. This makes their installation easier and reduces the cost. Moreover, it enables architects to exclude from their plans constructions which would tend to increase the risk of fire in the event of the house being struck by lightning.

"9. Special precautions are necessary in the case of thatched roofs. These consist mainly in keeping the conductors some distance away from the roof and in making the wire of such thickness that it shall not be destroyed at the point where it is struck by lightning. If this be done, a high degree of safety is attainable even in the case of thatched roofs."

HUNGARY.

Through the good offices of the Rector of the Royal Joseph Polytechnical University, Budapest, Dr. Moritz von Hoór kindly favoured the Lightning Research Committee in 1904 with the following remarks concerning the precautions against lightning then coming

into use in Hungary, showing the method of their installation, and their efficacy as proved by experience:—

"Up to the year 1892, in Hungary as well as in other countries, lightning conductors with collecting points according to the Franklin system were the only ones in use. Here, as elsewhere, the view was universally accepted that absolute security for the efficiency of lightning conductors was afforded by the largest possible cross section of the lightning rod by a slight change of the collecting apparatus, and by a good earth connection. It was held, therefore, that a conductor had been rightly set up when the collecting point and the earth had been connected by strong copper wires or cables, and care had been taken for a good earth contact.

"Experience of such lightning conductors, however, as well as observations systematically taken in England and the English colonies, and in Germany, proved that lightning rods on this principle did not answer their purpose, and in particular that the directions as to the area of protection of the conductor and the relation between height and base of the protected zone were of no practical value and quite baseless.

"It was repeatedly observed that there were lateral discharges from the conductor in the direction of the metal parts (badly connected apparently with the earth), that sparks leapt over curves in the conducting apparatus, and in general that buildings and other objects protected by the collecting points suffered damage from lightning, though to a far less extent, as shown by statistics, than objects altogether unprovided with lightning conductors.

"It was not until the beginning of the nineties that our views as to the function and the correct installation of lightning conductors became more clear, as a result of the investigations then made into electric oscillations, and of the right appreciation of the self-induction of lightning conductors.

"Following up the work of Hertz and Lodge, I was the first in our country to treat this question theoretically and experimentally in a scientific manner on the basis of the new principles, and was the first here to suggest the abandonment of the conductors with collecting points, and the introduction of contour conductors without collecting points, similar to Faraday's parrot cage.

"Leopold Stark, chief engineer of Messrs. Ganz & Co., has since made an exhaustive study of this question, and has worked out various practical plans for cage conductors, with a special view to their application to the protection of agricultural objects peculiarly exposed to risk from lightning (cf. *Villámhárítók különös tokintettel mezögazdasági epületekre*, irta: Stark Lipót gépészmérnök, Budapest, Fövárosi Nyomda, 1903).

"For some years now, as a result of these works and of the agitation started by the above-mentioned scientists, cage lightning conductors of this kind have been largely in use with us, both on town buildings and on agricultural objects. They consist, as Sir Oliver Lodge, and, long before him, Faraday suggested, of barbed wire, or strong iron wire, or sheet iron

bands, which, following the contours of the roof and building or other objects, conduct to separate earth connections or to connections joined underground by a circular conducting wire.

"The cost of such conductors is with us hardly more than that of the conductors with gilt collecting points and copper conducting wires, and they have been found admirably efficacious, as might have been deduced from theoretical reasoning; so that the military authorities both in Austria and Hungary have had all magazines of explosives protected in this manner.

"Special care is taken, in setting up these cage conductors, to avoid the sharp curves arising from a sudden change in the direction of the earth conductors, so as to reduce as far as possible the self-induction of the earth connection.

"Importance is likewise attached to good earths, but experience shows that if the cage arrangement is well carried out and the number of cage wires not too scanty, even without a very good earth connection the conductor still works satisfactorily.

"At present both the cage and the Franklin collecting point system are in use with us; but of late years, especially for agricultural objects, the cage system is coming more and more in vogue, and probably in a short time all the new conductors will be of this kind."

BELGIUM.

The Hotel de Ville at Brussels has been often quoted as the most perfectly and elaborately protected building in the world; however, it was struck in 1888 and set on fire, not because the conductors failed to carry off the stroke which fell on the building, but owing to the neglect or oversight of leaving a horizontal bar of metal totally unconnected with anything. This bar according to Sir Oliver Lodge did not even receive a side flash, yet the induced surgings set up on it were so violent as to ignite some gas and cause a small fire.

The Melsen system, which is largely adopted in Belgium, consists of a network of metal rods connected together at the top and furnished with an aigrette or bundle of eight 4 mm. copper rods spread out like a feather, so that the terminal points project so little above the horizontal conductor which runs along the roof that they can hardly be seen from below, but yet break up the area of the building so as to leave little space unprotected. Copper is used for the conductors, but where they descend, a special iron box is employed, in which they are embedded in zinc, and from this the down rods can be continued in iron and also connected to the rain-water pipes and other

ironwork of the building. The provision for earth connection is very ample, for instance, in the case of the Hotel de Ville there are 24 iron rods $\frac{2}{5}$ inch in diameter; of these eight are fastened to the spigot of an iron pipe 2 feet in diameter, which is suspended in a well in the courtyard, another third is connected with one of the principal iron mains of the water supply of the town, and the remaining series are taken in a similar way to a large iron gas-main.

FRANCE.

The Melsen system has been used to a certain extent for the protection of the public buildings in Paris, but French architects seem to prefer the long single point, probably because it is more easily adapted to the elaborate weather vanes and finials which are so largely used, presumably for the embellishment of buildings of importance. The standard rod or *tige* (Fig. 38), is 6 metres high, the diameter at base about 0·06 metre, tapering to nothing at the point; the rod is firmly connected to the woodwork of the roof, and the copper or iron conductor is fixed at the base by means of a shackle. The conductor is usually kept away from the building by means of supports, and is very carefully led into moist earth, or, in the case where the foundation is of rock, connected to a network of wires which run for a very considerable distance under the surface, with the idea of obtaining as large an area as possible. Where a well can be used, the earth connection is prepared by plaiting up galvanised iron strips so as to form a basket (Fig. 39), which contains a sort of grapnel which is attached to the conductor, the basket being filled with coke and lowered into the water.

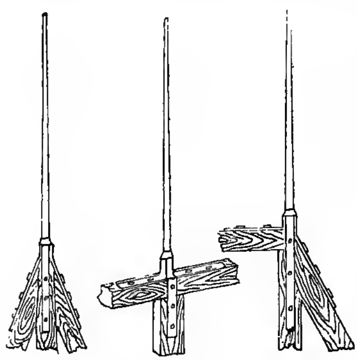


FIG. 38.

Horizontal conductors are always fixed on the roofs; the old method was to support an iron bar by means of stanchions, which were either screwed into the timbering or fastened by means of a flat plate. The stranded cable which has now taken the place of the solid rod is similarly held, and in both cases all the vertical rods are thus inter-connected.

FIG. 39.

ITALY.

Great attention has been paid to questions of protection, and nearly all the public buildings have had the older systems rearranged. The author recently visited St. Peter's Cathedral, Rome, and found that the method adopted is not unlike that which he specified for the very similar, though smaller, edifice of St. Paul's. Following the usual Continental practice, well-painted iron rods about $\frac{7}{8}$-inch diameter are run vertically at approximately equal distances round the building, and these conductors are kept away from the structure by distance pieces of marble, which are let into the stone-work at the galleries. Conductors are run horizontally in a similar manner all round, and united to the

FIG. 40—THE VATICAN.

various vertical rods; the dome is also protected, and the conductors are united to the small group attached to the cross, which stands at a height of 435 feet above the pavement. According to the theory of an area of protection, it would not have been necessary to protect the area immediately below, but the Italian authorities have wisely discarded the fallacious idea, and have encircled the structure by an iron network, which at various salient points is connected to high air terminals, each stayed by four guys. The position of the earths, which are formed in wells distributed at intervals round the building, is marked on marble slabs let into the walls. The adjoining

Vatican buildings, (Fig. 40) are also excellently protected—the high air terminals are built into stone-work projections evidently intended for ventilation, the system of iron conductors is clamped to the base of these vertical rods and is continued over the roofs, being kept away from the tiles by resting on marble supports, and at the end of each ridge an air terminal is arranged to project over the side of the roofs at an angle of about 60 degrees. The use of iron rod enables the protection of this the largest palace in the world to be

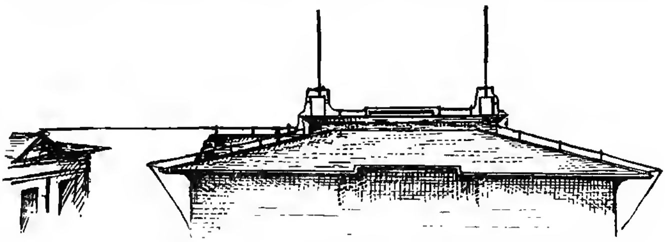


FIG. 41.

effectually shielded, at a cost which although large is trifling compared with copper. The quantity of material required for encircling the roof can be realised when one understands that the palace now covers an area of about thirteen and a half acres, of which about six are occupied by the twenty courts.

Fig. 41 is a sketch of the roof of a hospital at Naples, and illustrates the way the conductors are run over the building ; the system is connected to the adjoining wing by a small wire which crosses the intervening space.

CHAPTER VII.

EXAMPLES OF LIGHTNING STROKE ON PROTECTED AND UNPROTECTED BUILDINGS FROM THE LIGHTNING RESEARCH COMMITTEE'S OBSERVER REPORTS.

THE following are selected from observers' reports on buildings furnished with lightning conductors that were struck between the years 1901 and 1904. For the complete list see Appendix A, which also gives an analysis of each case, and the name of the observer.

No. 25. **Alexandra Hotel, Darwen,** July 21st, 1901.—The chimney which was struck is marked by a **X** (Fig. 42). The three lightning conductors of ¾-inch rope are shown. Formerly there were conductors on all the chimneys. These should be replaced.

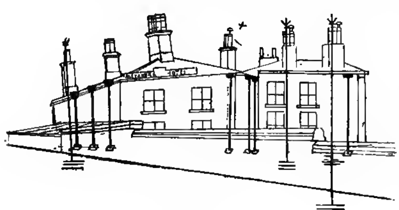


FIG. 42.

*NOTE.—If originally all had been interconnected by rods on the roofs and to the rain-water pipes the conductors would have taken the discharge.

No. 2. **Kea Church, near Truro,** March 1st, 1901.—Fig. 43. The portion of the stroke which fell on the vane was received by the conductor. The copper roofing of the spire was charged with a current probably of very high potential, as the lightning descended the rain-water pipe until it came opposite some lead flashing **L**, where it again divided, a portion going to earth by another rain-water pipe, **N**, while the rest passed along a small copper wire used for fixing plants (which was 9 inches away from the pipe), at **E**, back

*NOTES BY THE AUTHOR.

to the conductor and to earth, some of the copper from the wire which was fused being deposited on the copper tape. A woman who was in the church scrubbing the font, received an induced electric shock which knocked her down; she was probably touching a large metal ewer which stood on the ground.

NOTE.—The single lightning conductor (which was of modern design and in good order), attached to the vane 120 feet above ground, was not sufficient to carry off the induced charge from the roof. If all the rain-water pipes had been properly earthed and connected to the copper sheeting, the various alternative paths would have averted the damage. The path is indicated by the O O O circles and by the line H E.

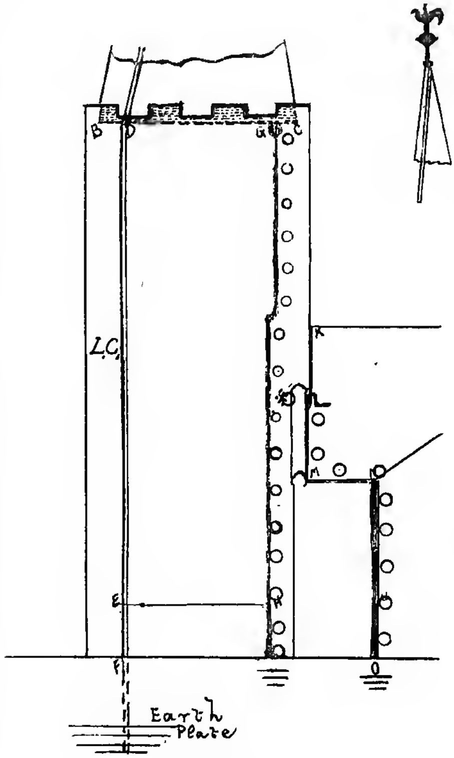


FIG. 43.

No. 28. **Chimney at Shire Oak Brewery, Walsall,** 20 feet high, standing 567 feet above sea level, July 22nd, 1901.—A conductor of copper tape fitted with multiple points on the elevation rod was fixed to the stack, which was 4 feet 6 inches square at top. The lightning struck the opposite side, and, after displacing the head, descended by the conductor, which it tore from its fastenings, heating a portion almost to fusion. Those in the neighbourhood were said to have received electric shocks.

NOTE.—It is not safe to depend on one conductor, especially if it simply terminates in a point and not in the manner recommended by the L.R.C., page 17.

No. 30. **Army Convalescent Hospital, Golder's Green,** July 25th, 1901.—Lightning struck the vane 2 (Fig. 44), which was about 1 foot 6 inches lower than point of conductors and about 20 feet distant.

NOTE.—The necessity of connecting all the ironwork as per Suggestions 2 and 5 of the L.R.C.

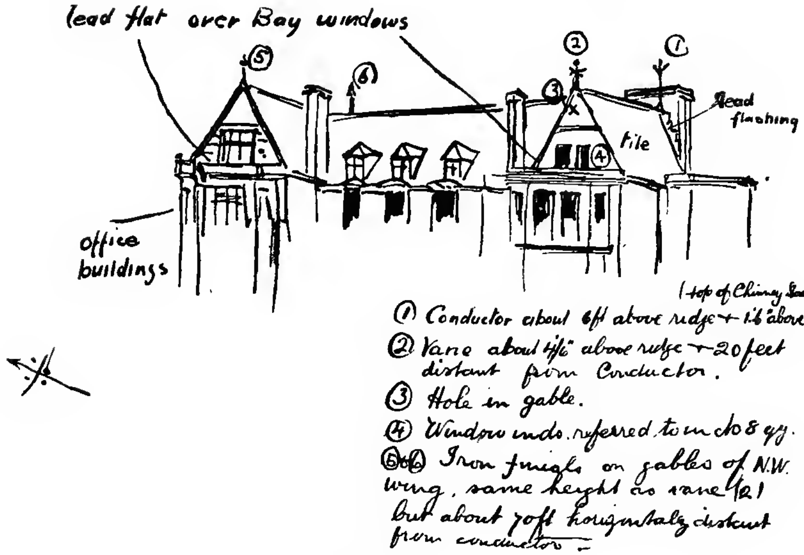


FIG. 44.

No. 54. **Stoerhead Lighthouse, Scotland.**—The flash struck the tower, but instead of following the lightning conductor a portion of the discharge passed by the brass speaking-tube **X** (Fig. 45), and divided at the point where the tube crosses the telephone wires, one part going direct to earth by the wires, the other part by the head bar of the iron bedstead and thence again into the wires, both finding earth at the

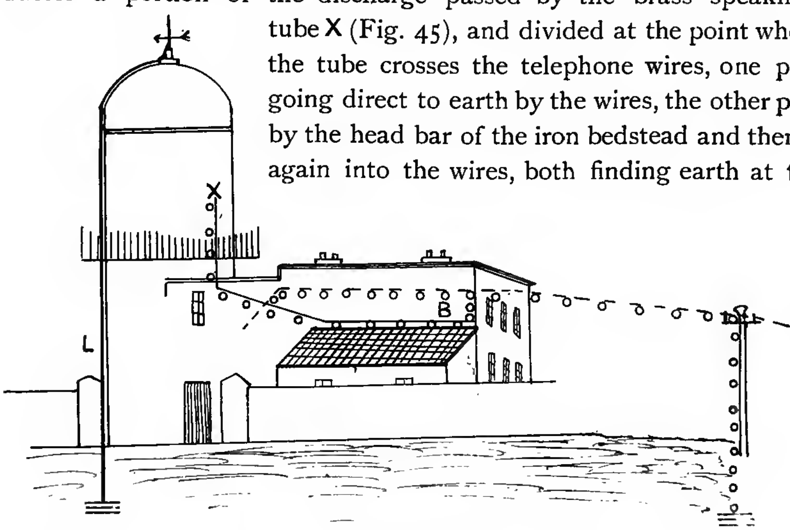


FIG. 45.

same pole. A hole about a foot in diameter was blown out of the brick wall near the bedstead, **B**; the earth wire of the telephone was melted.

NOTE.—This is a repetition of No. 56, and somewhat similar to No. 2, and shows that another conductor should have been run from the dome, also, that the iron railing should have had an independent earth.

No. 56. **Devaar Lighthouse, Scotland,** December 8th, 1901.—The lightning conductor of $\frac{3}{4}$-inch round copper rod was fitted to the gun-metal bracket of the ventilators; it had two conical platinum points, one of which was slightly fused, the other being blunted down for $\frac{3}{4}$ inch as if cut off. The two earth plates were each 20 inches by 10 inches by $1\frac{1}{8}$ inches, and were buried 8 feet from rail of towers. The current took a secondary course by the lead whistle-pipe for 30 feet, where it reached the dwelling house, damaged roofs, and descended by lead down pipe to some underground water tanks, blowing off their covers.

NOTE.—A single conductor will not carry off a B flash, especially if there is a copper dome as on the above. The whistle-pipe should have been properly earthed.

FIG. 46.

No. 57. **Chimney Stack, Stricklands Brewery, Rochdale,** December, 1901.—The high chimney was struck during a heavy hailstorm; the air terminal of three points was found hanging over the top. The rod was continuous, but where it passed the base of the stack, it was insulated from an iron strengthening band, leaving a space between the insulator and band of half an inch. The chimney was cracked in much the same way as Fig. 46, the bottom of the fault being near the roof of an adjacent shed. The stack had to be taken down.

NOTE.—Instead of being insulated the rod should have been connected to the iron band; it would have been advisable to have run a second

conductor on the opposite side of the stack, but at any rate the band should have been independently connected to earth. See page 17.

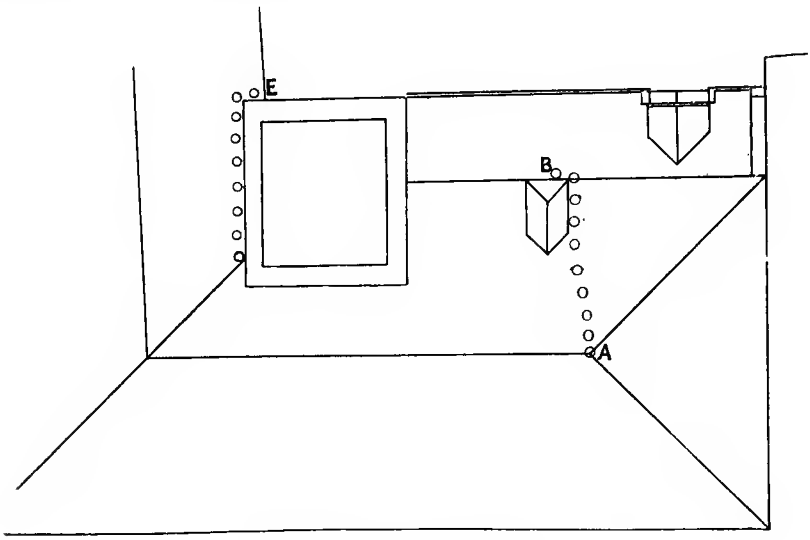


FIG. 47.—PLAN OF ROOF.

No. 64. **Cavendish Laboratory, Cambridge,** July, 1902 (Fig. 47).—A conductor of $\frac{3}{8}$-inch rope was fixed to the tower and went to earth at E; the main stroke followed the conductor, but a side flash struck the hip knob A, about 40 feet away, and made its way to the lead cheek of the dormitory, and at its lowest point B earthed by following a small compo gas pipe (which was laid just below the sill), which it pierced on its way.

NOTE.—The conductor was fixed on the old idea that because it was on the tower it protected the roof, whereas the hip knob should have had a separate earth connection. If the gas had not been turned off at the main, the building would probably have been set on fire.

No. 65. **All Saints' Church, Maidenhead.**—A lightning rod of $\frac{3}{8}$-inch round iron projected 6 feet above the top of the spire, and was continued to the iron tie in spire, thence a $\frac{1}{2}$-inch copper rope ran to the ground (Fig. 48). The cock was knocked off spindle and fell; spire damaged; a hole 18 inches deep made where conductor entered ground; brickwork at foot of tower chipped; no rain.

NOTE.—It was incorrect to use the support of the finial as a conductor, which should have been taken up outside the spire and there connected to the iron rod. This is an example of a conductor, evidently having an imperfect earth, acting sufficiently well to prevent serious damage to the building.

No. 66. **St. Andrew's Church, Marks Tey,** June 7th, 1902 (Fig. 49).—The weather-cock, to which the copper rope was attached, was displaced, and earth much disturbed, and gully broken at **X**; the rod took the discharge.

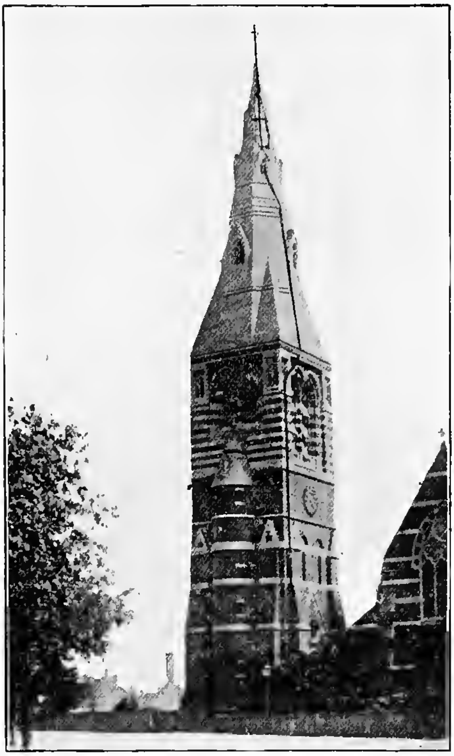


FIG. 48.

NOTE.—The stroke (*not a very severe one*) was mitigated by the heavy rain. Had a B flash occurred there would have been more to report. The displacement of the weather-cock was probably due to faulty connection between the conductor and the spindle of vane. The badly-arranged earth connection is to be condemned.

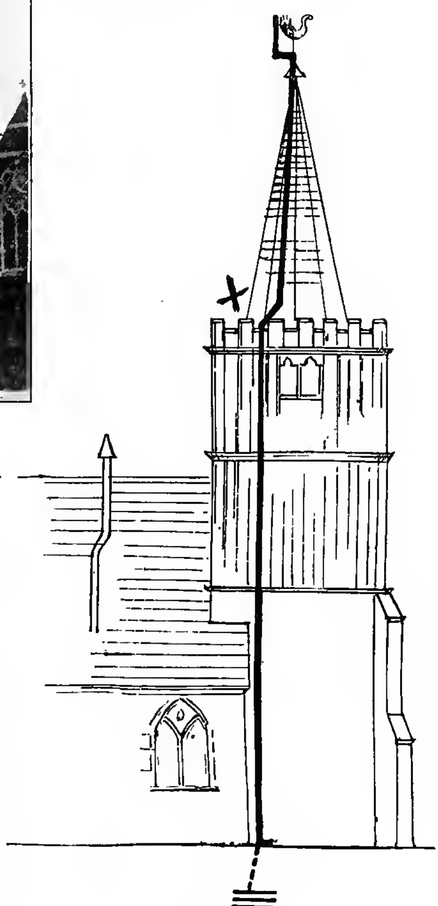


FIG. 49.

No. 67. **Near Heathfield, Sussex.**—This house, which had lightning rods fixed on every chimney, was struck in June, and again in August, 1902. The latter stroke is an example of a divided B flash, part of which fell on a chimney stack, bending the rod as shown on Fig. 50. A small unprotected statue about 40 feet

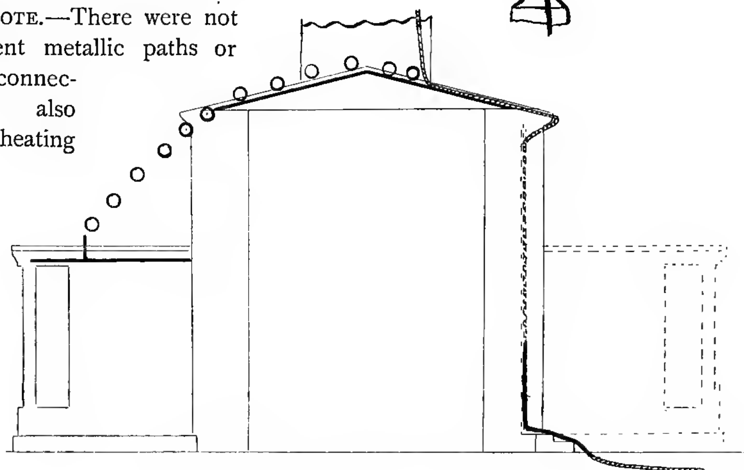
away was destroyed at the same time, the flash going to earth by the roof of a conservatory. It was raining heavily, and the conductors were in good order.

NOTE.—The futility of relying on individual rods without some system of inter-connection (see suggestion L.R.C.) is practically demonstrated, also the necessity of connecting up the smallest piece of metal work, as the iron support of the statue was selected in preference to the adjoining rods, whose air terminals were considerably higher. The circles o o o show the paths of the discharge.

FIG. 50.

No. 68. **St. Pancras Church,** July, 1902 (Fig. 51).—The $\frac{5}{8}$-inch copper conductor was run from the spire, being looped round the square base of the gun-metal cross; the earth connection was made by curling the cable and burying in charcoal. That the main flash travelled by the conductor was proved by the disturbance to the soil and the damage to the neighbouring cast-iron gas pipes, the lead packing being torn out, causing large escape of gas. The oscillatory discharge on the conductor caused a side flash to the iron radiator pipe, which slightly projected above the lead flat, the rather higher zinc cowl being untouched. The path was then made by the radiator along the lead supply pipe to the feed cistern (fusing on its way a compo gas pipe and igniting the gas), then

by the overflow pipe to the gully on the right (Fig. 52). The electric fuses in the church were destroyed.

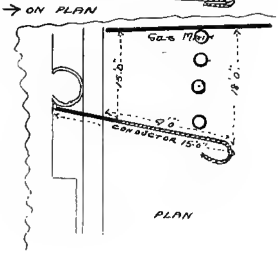


FIG 51.

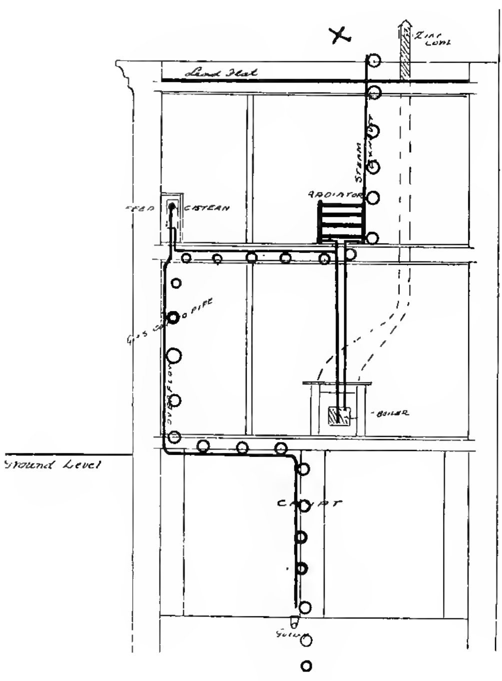


FIG. 52.

NOTE.—There were not sufficient metallic paths or earth connections; also the heating system was not earthed. This is an example of the usual form of lightning conductors acting as well as could be expected under a moderate discharge; if a B flash had occurred, in all probability the lower portion of the building would have been greatly damaged and set on fire. Looping the cable which formed the earth connection is to be condemned; also, the position of the earth should not have been fixed so near the gas main.

No. 78. **Inverness Post Office,** August, 1900.—One conductor of $\frac{7}{16}$-inch strand copper projected above the roof and was earthed by soldering to a 12-inch water main. It was tested shortly after the occurrence, and found to be in good order; the resistance was about one ohm. The building was marked in several places and set on fire. On the east mansard roof it split the lead that covers the flat top in six places; the two larger splits, 28 inches long each, were as if burned, the two shorter ones were like cuts with a knife. Below the west roof two discarded gutta-percha wires reached from the ceiling of a room on the third floor to within a foot of the iron hot-water pipes. The fire was caused by the lightning passing by these wires, setting fire to the gutta-percha and the wood lining of the room. The pole on which the conductor was fixed also supported numerous telegraph wires. The conductor did not appear to have been struck.

NOTE.—This is a very interesting case, showing that the number of telegraph wires do not afford protection to the roof on which they are fixed, and that it is necessary to connect the lead flats and iron portion of the building independently to earth as recommended by the L.R.C. Suggestion 6.

No. 83. **St. Michael's Church, Highgate,** January, 1903.—The cross was struck, and one arm fell through the roof, the conductor, $\frac{5}{8}$ inch diameter, was not damaged. The spire has been struck twice before, in 1856 and 1885.

NOTE.—It appears that the copper dowel holding the cross was connected at the bottom of the spire to the conductor, but not at the top. A spark therefore took place through the stone work to the holdfast of the outside conductor, naturally splitting the cross. The cost of the repairs in 1885 is said to have been £200.

No. 86. **Ainsworth Mill, Lancaster,** February, 1903.—The buildings consisted of a stack, about 60 feet high, 15 feet square at base; adjoining this was the engine-house. A conductor was on the chimney on the north side and ran to earth near the water lodge. The flash struck the chimney, the lower part first giving way, crashing through the engine-house, and completely burying the engine. Bricks were thrown violently in all directions, and for a radius of 300 yards scarcely a house escaped without a number of broken windows. Fig. 53 shows the exterior of the engine-house after the stroke.

NOTE.—There is some doubt as to the continuity of the conductor; if this was imperfect, it would account for the breakage where the stone base joined the brickwork.

FIG. 53.

No. 88. **St. Paul's Church, Bedford,** March 14th, 1903 (Fig. 55).—The lightning followed the conductor to the base of the spire, and then passed by the rain-water pipes, which are in different positions round the building. Most of the rain-water pipes are of cast iron, the others are of lead. The iron pipes are in several sections, and almost every one was more or less damaged or loosened. In several places they were broken at the joints and at the bottoms, whilst some of the lead ones were bulged as Fig. 54. The lead flashings of the opening through which the water runs from one roof to the next pipe were broken or twisted out of shape. On the roofs some of the lead flashings have been torn away from the walls. But the tremendous force exerted by the lightning can be better judged by the damage it caused inside the church. Passing through the roof at the south side of the tower, it moved, some three inches or more out of its place, the stout beam running along the top of the wall of the Lady Chapel; while in the choir vestry on the other side of the church another thick beam was forced a quarter of an inch from the wall, and one of the stone corbels supporting it was split through. The lightning also found its way into the small room at the end of the church and next the vestry which was formerly used as a dynamo room. In this chamber it tore from the wall an electric

FIG. 54.

light bracket, and along the wire the lightning ran to the switchboard fixed in the church on the outer wall of the choir vestry. Here it fused the main switch, so that no light could be obtained until it was repaired. The fabric of the church itself fortunately escaped damage beyond the decayed stone work being chipped here and there.

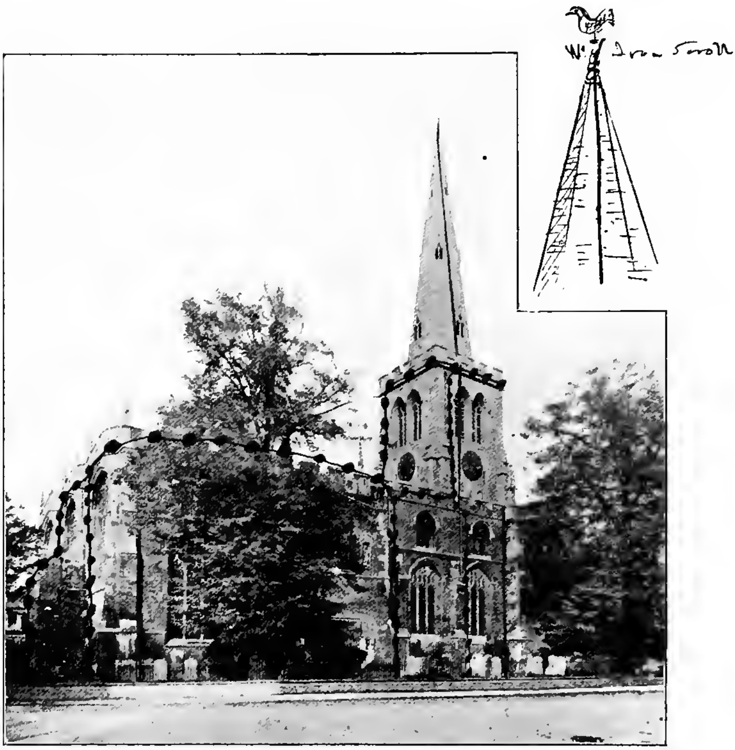


FIG. 55.

Pieces of roof were thrown 50 yards across the road through the Corn Exchange windows. Where the lightning ran down the lead pipes it did not fuse them.

NOTE.—The oscillations set up in the copper conductor were distributed all over the roof, as there were no subsidiary conductors to form a path to earth, the current followed the lead flashings and descended by the rain-water pipes somewhat in the manner indicated by the O O O circles. All these pipes should have been connected to a horizontal conductor on the roof and again inter-connected near the ground.

No. 93. **Tower of Coatbridge Church, Coatbridge,** August, 1902.—The upper half of the tower is octagonal. The height from base to top of the eight cone-shaped stone balusters, **A**,

Fig. 56, is 80 feet. The conductor of copper wire rope (seven $\frac{1}{8}$ inch strands), ran from one baluster, **A**, to ground in a vertical line, fixed with metal holdfasts carrying glass insulators, **I**. The air terminal, with four points, **C**, projected well above the one baluster, and in addition there was a length of the same wire rope placed round the coping at the top of the tower, immediately below the eight balusters. This portion of the conductor had no insulators, and a loop was made at one end as shown in plan on Fig. 56, and the other was attached to the conductor. The lightning first struck three of the balusters, avoiding the air terminal, demolishing them, and passed by the horizontal cable, fusing it at the loop, to the main rod and to earth. There was no disturbance at the ground, the earth connection being good, but about 30 feet down from the air terminal a piece of stone, midway between two glass insulators, was splintered. The points of the air terminal do not appear to have been struck. Considerable damage to the roof was occasioned by the falling stones, and the necessary repairs cost £600 to £700. The position of the three balusters which were destroyed is shown by x x x and the path of the flash by o o o

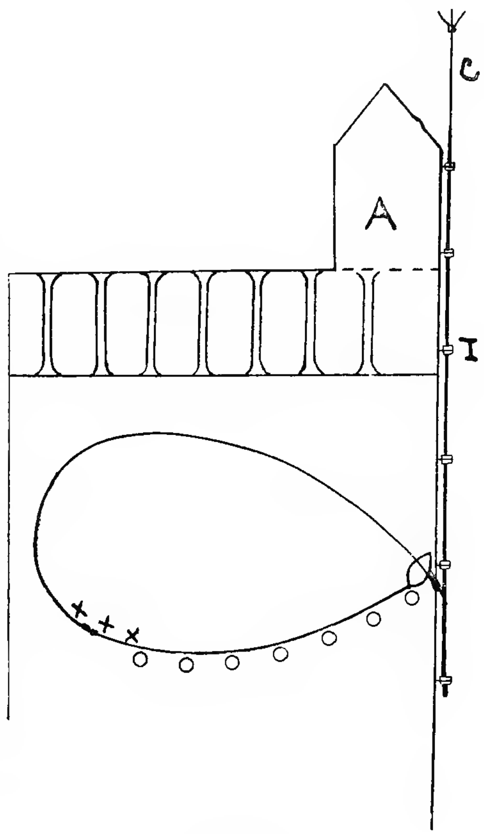


Fig. 56.

Note.—According to ordinary practice the tower would be considered protected, however the three points without conductors were selected. If a small wire had been run from the loop to the top of each baluster the lightning would have passed by the rod. The splintered stone was caused by the rod being held in insulators.

Victoria and Albert Museum, August 17th, 1900. Observer: General Festing, Member Lightning Research Committee.—An electric light main was struck, and the lead covering of the concentric cable was burnt away for a space about 3 inches by 1 inch, at a point where it rested on the parapet, alongside the edge of the gable. There were holes in the lead flashing and marks down to the lead stack pipe. The insulation between the conductors was apparently not injured, but a short circuit was found in a junction box.

NOTE.—Apparently this was a side flash from the lightning conductor, which was on a high chimney stack, the flash passing by the roof to earth and part of it entering the cable. Where lead-covered cables are thus exposed, it would be desirable to earth the outer covering in several places.

Hanslope Church, near Stony Stratford, April, 1904. Observer: W. P. Goulding, F.S.I.—¾-inch copper tape conductor, let into chase in the tower face and carried through wall into the inside. One of the lower spires on the tower, immediately beneath the spire, was struck and the pinnacle destroyed.

NOTE.—Leading the conductor inside the building is to be deprecated, but the belief in an area of protection and consequent absence of any conductor on the lower spires caused the damage. A conductor let into a chase is not so effective as one held a short distance away from the structure. L.R.C. Rule 3.

Congregational Church, Queen's Road, Weybridge, struck March 20th, 1905. Observer: Arthur Goulding, F.S.I.—"The lightning conductor was one of Spratt's, put up in about 1860. It consisted of woven copper wire strands (about twelve in number). It was fixed to the rod at the top with a small copper tube, in which the wire was connected by a rivet, and was run about 2 inches from the walls by copper stays with glass insulators, lined with zinc. The tube was broken away and found lying on the ground, and the lightning conductor was hanging from the top. The effect of the shock on the conductor was to draw the strands tightly together in a zig-zag shape. No damage was apparently done to the steeple, but the gas fittings inside the church were affected, and the hot-water pipes broken in three places. The conductor descended to earth and was carried into the ground about 10 feet from the building, passing under some gas pipes in the church path. The current apparently went from the conductor to the gas pipes, the collar of one

of them being broken, and in my opinion was conducted along the pipes to the interior of the church. A curious feature in the case is that in the schoolroom, which is a detached building standing some feet from the church, a compo pipe in the wash-house, which is in the back of the schools and furthest away from the church, was fused and the gas ignited, and was discovered alight by the caretaker in the morning, having apparently been burning for about eight hours. Fortunately, there was no inflammable material near to it."

NOTE.—This form of conductor is one which cannot be too strongly condemned; however, singularly, in this case it preserved the fabric, although the conductor itself was destroyed.

St. Botolph's Church, Cambridge, unprotected. Observer: W. Fawcett, M.A.—The lightning struck the south-east pinnacle **A**, ran down a rusty iron rod on to the lead roof **B**, from there it went to the lead fall pipe **C**. At **D** the lead had been changed to iron, and here it blew a hole about 1 foot 6 inches by 6 inches deep out of the wall with such force that a piece of stone broke the wall at the side of the buttress at **E**. (Fig. 57.)

NOTE.—This clearly shows how the rain-water pipe acted as a conductor, and had it been continuous the damage would have been confined to the destruction of the pinnacle.

Rockliffe Church, Carlisle, November 8th, 1899, unprotected.—The Church, which is on

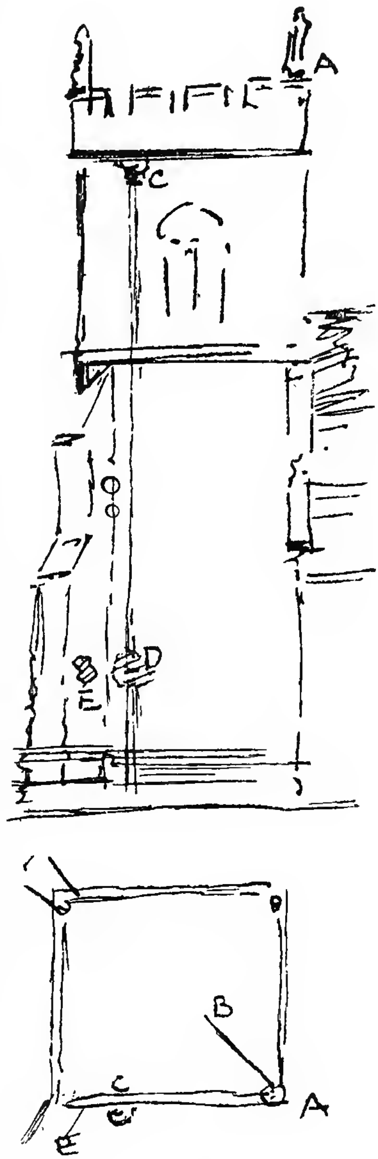


FIG 57

an exposed position overlooking the Solway Firth, was almost wrecked; the steeple was struck at its base, where it rested on a tower about 50 feet high. Most of the débris fell through the roof, forcing the windows outwards by reason of the compression of the air. Stones were hurled in all directions up to 100 yards, one being found in a field nearly 200 yards from the spire. The damage was estimated at £2,000.

NOTE.—This was doubtless the result of a B flash, and shows the explosive action which may occur. The disastrous results could only be minimised by the most complete system of protection.

Godshill Church, Isle of Wight, January, 1904. Observer: Arthur Goulding, F.S.I.—Fig. 58. The lightning, missing the flagstaff, struck the pinnacle and parapet, passing between the latter and the lead flat forming the tower roof, which was uninjured, acted as an explosive inside the tower, destroying the stairs, clock casing (marked A), and deal panelling, falling on the tower arch next to the nave, broke

FIG. 58.

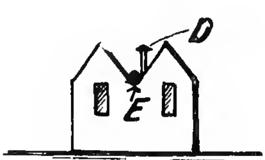


FIG. 59.

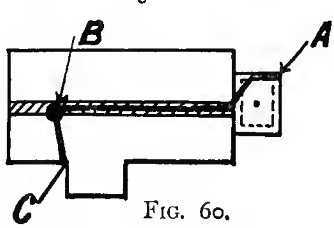


FIG. 60.

all the windows, dislodged the basin of the font from its pedestal, doing minor injuries inside the building. The walls of the tower, 3 feet thick, were forced open at the quoins, and the clock face blown some 50 yards from the tower.

NOTE.—The course of the flash is shown by the dotted line, and the case is interesting for two distinct reasons: First, that the high flagstaff, with metal vane, which certainly was a more salient feature and a better conductor than a stone pinnacle, was untouched, and, secondly, although the church had been previously struck in 1778 and in 1897, the insurance companies have not insisted on any system of protection. Fig. 59 is the end elevation; **D** is the stove pipe (part of the flash went to earth near the base of this pipe); **E** is a lead gutter; Fig. 60 is a plan; **A** is point of first contact; **B,** stove pipe; **C,** damp place where earth was found.

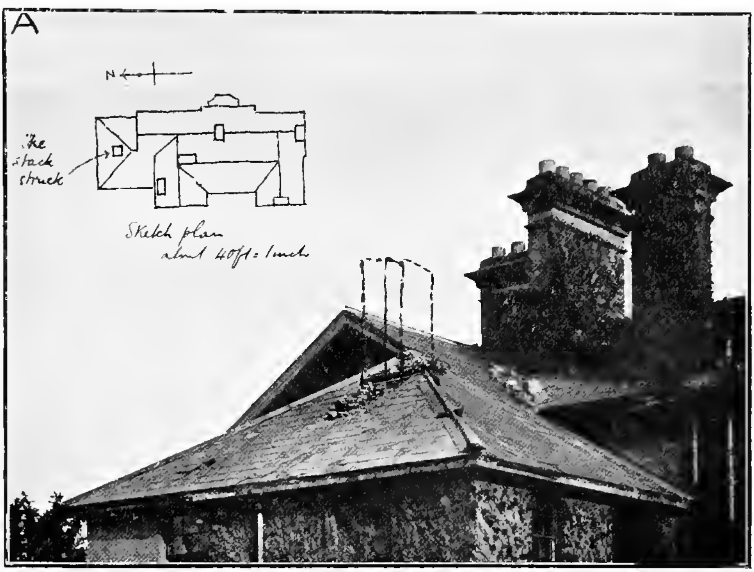


FIG. 61.

Southborough Vicarage, Tunbridge Wells, May, 1903. Observer: C. H. Strange.—Detached building standing on a hill about 400 feet above sea level. The mechanical effect of the discharge was very great, the chimney struck being indicated by dotted lines, Fig. 61. It then blew out the face of the chimney breast in the bedroom below, as shown in Fig. 62, where **B** shows position of the bedstead, and finally wrecked the fireplace in the dining-room immediately under. During the same storm a number of the

incandescent lamps (unlighted) had their filaments broken. The photographs are by Lankester, Tunbridge Wells.

Hanslope Parish Church, near Stony Stratford, Bucks, struck, April, 1904. Observer: W. P. Goulding, F.S.I.—This church is provided with a $\frac{3}{4}$-inch copper tape conductor let into a chase in the tower face, and carried through a hole in the tower wall and thence up the spire. The four pinnacles have each a revolving copper vane. Side flashing from or perhaps avoiding the conductor, the lightning struck the north-west pinnacle, dislodging a piece of stone about a foot cube from the apex and squeezing the copper vane out of shape, doing no further damage.

FIG. 62.

NOTE.—The failure of the tape conductor was mainly due to its being run inside the tower wall; also, its utility was lessened by being let into a chase instead of being carried on holdfasts outside the structure as recommended by the L.R.C. Rule 3.

The Grange, Ramsgate, May, 1904.—This house consisted of three floors, surmounted by a tower on which there was a higher portion holding a flagstaff. The stroke passed by the wire guy-stays of the latter, and set the roof on fire. The damage incurred was said to be about £2,000.

NOTE.—The folly of erecting a flagstaff, especially as arranged with disconnected supports, without a lightning conductor, is shown by the destruction of one of the few architecturally elaborate residences in Ramsgate.

Cirencester Station, Oct. 1901. Observer: C. Hooker, Surgeon.—Chimney split at X, large hole, B, in roof of porters' room, glass roofing of platform below D much broken; lightning went to earth by rain-water pipe, E, and iron column, G. T is a water

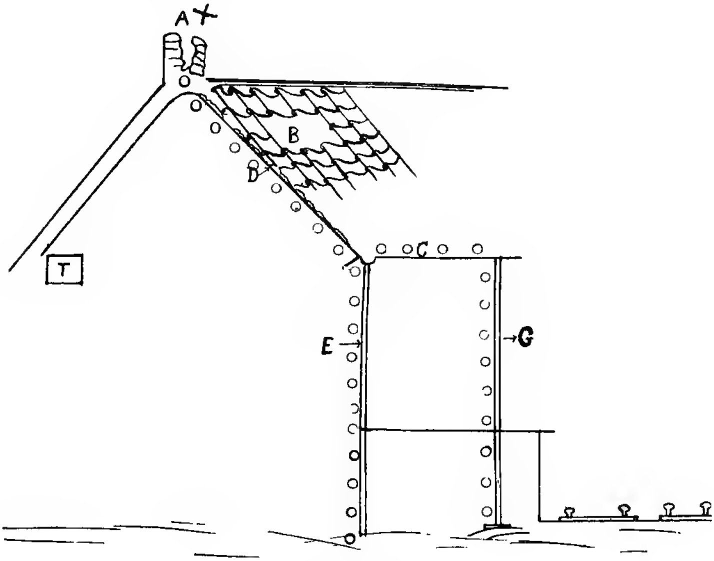


FIG. 63.

tank. Fig. 63 is from the observer's rough sketch; the o o o show the direction of the flash, which was probably dispersed by the rails which are on the right.

NOTE.—Stations are not often struck, owing to the protection afforded by the numerous overhead wires; the good earth by the rails probably prevented the flash from spreading laterally.

No. 45. **Cottages near Lewes, Sussex,** August, 1901. Observer: H. C. Card.—Fig. 64 is taken from a photograph of the interior of the upper room of a cottage where two people were sleeping. The progress of the flash from the base of the chimney (shown by dotted lines) is illustrated by the dark marks on the plaster; probably only a small portion of the flash entered the room, escaping by perforating the sides of the roof in several places. The bedsteads do not appear to have been touched; although it was said that "the occupants were thrown out," they more likely jumped out in their fright, as they were not severely hurt. The ceiling was on a slope from B and C upwards.

No. 6. **All Saints, Bramham, Yorkshire,** May, 1902. The tower was very much wrecked; only one flash, and no rain until later. The church had been previously struck, and bells damaged, in 1827.

NOTE. — The damage is of the kind which usually occurs with similar unprotected buildings; the point of interest is, as at Hutton Bursal, No. 50, Ipstones Church, and Godshill Church, the flagstaffs, with weather vanes, were not struck, the lightning falling on the upper part of the respective towers.

FIG. 64.

No. 10. **Sewer Ventilating Shaft, Camberley,** June, 1901.—The iron shaft, 20 feet high, was supposed to have acted as a lightning rod; the stroke branching off among the drains in all directions, lifting a manhole weighing 2 cwt., and displacing it about 12 feet.

NOTE.—As the house on the opposite side of the wall was struck, and the wall itself broken down, it is probable that the flash divided, the house and the shaft being struck at the same time. To avoid similar damage it would be quite easy to run a conductor from the base of the shaft into moist ground.

No. 13. **Upper Parkstone, Bournemouth,** June, 1901. Observer: J. F. Fogerty, A.R.I.B.A.—The lightning struck the chimney stack at **X**, entered roof at **B**, passed to guttering, blowing off slates, thence to gutter, **G**, and to earth by rain-water pipe, which

was fractured at joints. See Fig. 65.

NOTE.—This case is quoted because it shows the general course of a flash, and how easily the damage could have been prevented by running a few small conductors from the top of the chimney to the guttering and rain-water pipes; the latter prevented further damage by acting as a lightning rod, but as the joints were not bonded as recommended at page 29, their joints at the sockets were broken.

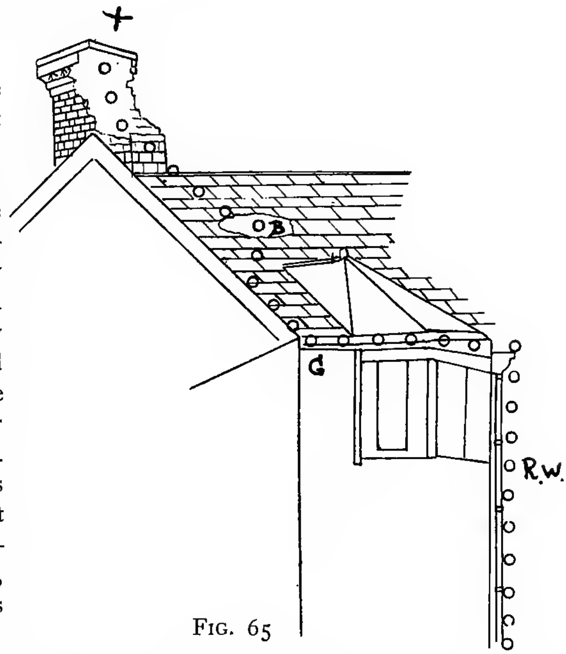


FIG. 65

No. 21. **Shop, New Road, Chatham,** July, 1901. Observer: T. S. Addenbroke, Surveyor, War Department.—The apex of gable struck; the slates were pierced and the lightning followed the path of a ½-inch gas pipe, which it fused for about 12 inches, setting the building on fire, earthing through the gas meter, which was not damaged.

NOTE.—Here the small gas pipe offered a better path than the ironwork outside the building. This ought to have been connected with the ridge of roof and gable.

No. 17. **Gardener's Cottage, Camberley,** July, 1900. Observer: G. B. Hartfur.—The builders were at work fixing the chimney pots when the lightning struck a scaffold pole considerably higher than the stacks, and at the same time the angle of the chimney stack, throwing the bricks some distance but leaving the newly-set pot undisturbed.

No. 22. **Greenhouse, South Shields,** July, 1901. Observer: A. T. Flagg, Schoolmaster, who has furnished sketch, Fig. 66.—A glass-house, wires running from end to end just under the glass roof, one end nearly touching the last of a row of small trees. The leaves at **A** were singed, the lightning left a

track on the paint of the wooden knob **B**, broke the windows at **C**, split the wood under **B**, travelled along one of the wires, ripped the woodwork near **E** to get to the zinc pipe **H** and to earth; at **E** an iron rod screwed to the post was forced away.

NOTE.—This is a very interesting case, showing that the higher tree was ignored and the small wires perfectly conducted the flash without fusing same, and if they had been in contact with the pipe **H** probably even the glass would not have been broken.

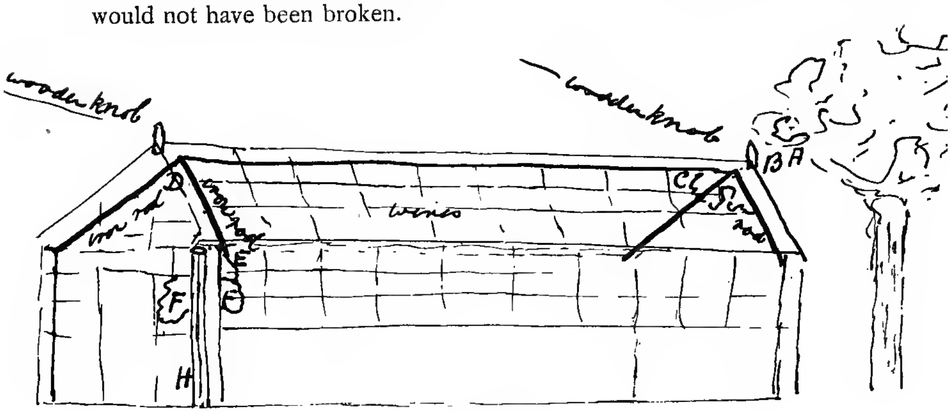


FIG. 66.

No. 27. **Palmerston House School, Ross,** August, 1901. Observer: Mrs. Evans, Principal.—This large stone building, the highest house in the immediate neighbourhood, was struck about 2 a.m., the lightning damaging the roof, Fig. 67, just above

FIG. 67.

where four boarders where sleeping; they were uninjured, but the furniture was considerably damaged.

NOTE.—The comparatively small damage was probably due to the very heavy rain, which allowed the greater portion of the stroke to escape down the walls, while a side flash only entered the building.

No. 31. **Tannery, Hylton Road, Worcester,** July, 1900. Observer: A. B. Pinckney, R.I.B.A.—The chimney of the front office, a two-storied building adjoining an open space covered by an iron roof; on the other side of this was a high brick building used for storing bark, and a factory chimney 90 feet high. Ignoring the weather cock, which was close to, but much higher than, the office chimney, the latter was split off, the flash following the lead on the roof to the iron roof, earthing by the iron stanchions without further damage.

NOTE.—The protection afforded by the large metallic surface of the iron roof dispersed the flash, which otherwise would probably have blown out grates, &c.

No. 32. **Dwelling House, Sutton,** July 1901. Observer: H. Gilbert.—Semi-detached villa. The chimney took the stroke; it then entered sleeping room, setting fire to clothing of servant (severe burns to legs), tore out register, fractured mantel, passed to first floor, destroying mantel, and earthed by small gas pipe, laying bare the plaster. Slate roof, iron eaves, gutters, back and front.

NOTE.—If a rod had been led from the top of the chimney stacks over the ridge of roof to the guttering on each side, the rain-water pipes would have saved the damage to the interior of the house.

Nos. 57A and 95 are very similar.

No. 36. **Wesleyan Chapel, Springbourne, near Bournemouth,** July 1901. Observer: J. F. Fogerty, A.R.I.B.A.—A Boyle's ventilator was struck and knocked off, no interior damage.

No. 26. **Bridge of Weir Gas Works, Renfrewshire,** July 1901. Observer: Captain Lloyd, R.E., Inspector of Explosives.—There were several stacks to these works, all surrounded by houses higher than themselves, the newest and tallest stack was damaged, there were two holes in the chimney, one about 3 feet below the top, the other 8 feet lower, on the side which *faced the wind.*

No. 42. **St. Stephen's Church, Carnoustie,** August 1901. Observer: J. P. Bruce, Architect, who gives sketch, Fig. 68.—The stone cap of belfry was dislodged, the lightning passed inside along chain pull of bell, which it broke, then escaped through the rose window, part of the king post in roof being broken away; another part of stroke earthed inside by means of a gas pipe.

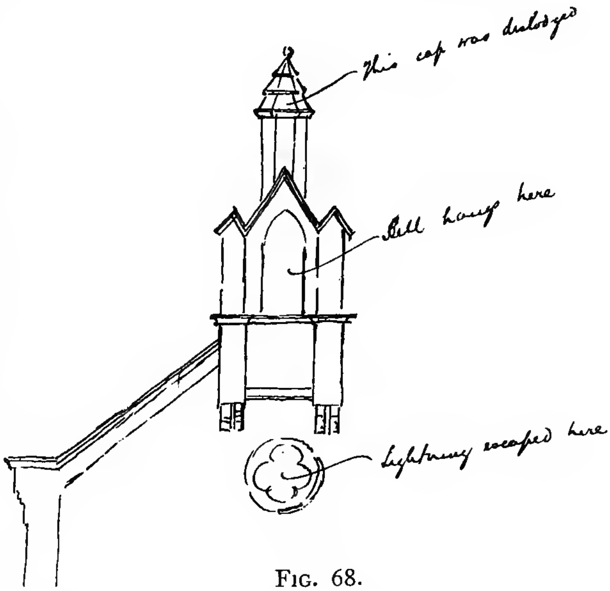


FIG. 68.

NOTE.—The path through the window is explained by the great resistance set up by the chain, each link of which would act somewhat like the coherer used in wireless telegraphy, and impede the current.

No. 32A. **Villas, Hayward's Heath,** July 1901. Observer: Dr. Lee Jardine.— The flash destroyed chimney and part of roof and passed by rain-water pipes.

No. 43. **Gordon's College, Aberdeen,** August 1901. Observer: The City Firemaster.—A building of two floors surmounted by an iron finial. The lightning entered the building and destroyed the electric light wires and telephones. No displacement of stones or slates.

NOTE.—This was doubtless an A flash which found a ready path to earth by the electric circuits, as it destroyed the main fuses and their box.

No. 54A. **Cadet Armoury, Boston, Mass.,** June, 1902. Observer: W. G. Preston, Architect.—The flag pole, 110 feet long, about 1 foot diameter at base, fixed on the top of a fireproof building containing a large amount of steel work. The pole was much

splintered, see Fig. 69, but no further damage occurred. It was reported that the flash was seen passing from one iron portion to another.

NOTE.—This is confirmatory of the opinion that lightning striking iron-frame buildings is often dispersed without damage to their structure.

No. 51. **Sherwood Street, York,** August, 1901, Observer: W. J. Cudworth, Engineer, North Eastern Railway. — End house of a row. Chimney struck, flash descending by slates, stripping same from ridge to rain-water pipe for a space of 4 feet wide.

NOTE.—The lightning took its usual course, and there would have been probably no damage at all if an $\frac{1}{8}$-inch diameter iron wire had been run from the chimney to the pipe. It is interesting to note that as No. 44A and several other cases it was the end house that was struck.

FIG. 69.

No. 44A. **Dwelling House, Conway,** August 1901, Observer: G. M. Lee, Engineer, Postal Telegraphs.—This was the end house of a row. The lightning knocked off the chimney, entered the house, and burst out the brickwork about 12 feet below the roof. No fire, bricks thrown 31 yards.

NOTE.—In similar previous cases the damage has been less, owing to the flash taking the guttering and rain-water pipes; in this instance there appears to have been no metal work outside.

No. 57A. **Cubbington, Warwickshire,** February, 1902.—Workmen's Dwellings, School House and Residence. The lightning spread over the roofs of these low buildings, earthing by the rain-water pipes.

NOTE.—The interesting feature of this case is the effect of one portion of the flash, which perforated the brick wall ($1\frac{1}{2}$ bricks thick) of the schoolmistress's house, where the pipe hook supported the gutter. It made a hole about $\frac{1}{2}$ inch wide, then jumped to a nail on which a small gilt frame was hanging, playing over the gilding, which appeared as if washed off; it then again pierced the wall near the bottom of the frame and escaped by the pipes. The Fig. 70 is taken from a photograph of

FIG. 70.

the wallpaper and shows the holes where the flash entered and left the room.

No. 90. **Greenfield, St. Mellons, Monmouth,** May, 1903. Observer: H. Heywood.—Dwelling house. "The effect as if an explosion," the chimney stacks being blown right and left, one piece of stucco being

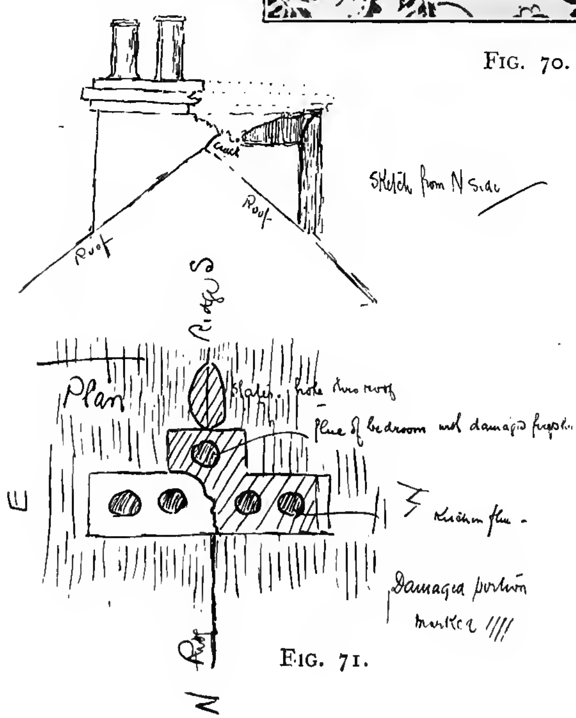


FIG. 71.

picked up 120 feet from chimney. Ridge tiles destroyed, flash passing down the flue; the grate displaced 5 feet, iron chimney-piece overturned. (See Fig. 71, which shows part elevation and plan of chimney).

NOTE.—The plan shows how necessary it is to protect the ridge of roof with horizontal conductors as recommended (see L.R.C. Suggestion 2). The interior damage is similar to that shown by Fig. 62.

No. 94. **Torr Head Coastguard Station,** August, 1903.—The actual low building was not provided with a lightning rod, but very near it a flag post, 50 feet high, had a copper conductor, $\frac{1}{4}$ inch diameter, projecting over the top, and a telegraph pole was close to the building. In the plan (Fig. 72) **A** is the flagstaff, **B** the telegraph pole. The building was damaged; coastguard who was standing at door **C**, injured.

NOTE.—This shows that no reliance can be placed on the shielding effect of a conductor fixed to a higher point, and the station ought to have had a separate rod.

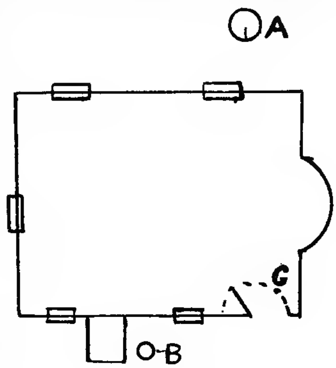


FIG. 72.

No. 32B. **St. Dunstan's Church, Mayfield,** July 1901. Observer; Rev. G. Kirby.—Spire struck, ripping off many of the shingles; part of the flash entered the roof of the spire, wrecking the beams, cutting a piece 4 feet long out of a stay, then to earth at base; the other branch ran down the roof to an iron gutter on north side of nave until it came to a stove pipe, 60 feet away, where it descended into the church and earthed, smashing up the floor as if a small mine had exploded. Damage came to £50.

School of Art, Birmingham, 1900, *Protected.* Observer: E. R. Taylor.—A ventilator on the gallery was struck near the conductor, which descended the wall from the higher part of the adjoining building. The rod was tested, and found to be in good working order.

Nobel's Explosives Company, Ardeer, Ayrshire, 1900.—The author had occasion to investigate the cause of the explosion of two of the detached buildings used for manufacturing gun cotton, and confirmed the opinion that it was due to lightning. The two buildings struck were not provided with conductors, and it appeared that the first one had received a direct flash, and the second,

which was some distance away, an induced current conveyed by the overhead electric light wires, which passed near both structures. The latter effect was probably facilitated by the leaden floors, which became charged, and sparked to some of the machinery used in the manufacture, and thence to earth.

An interesting example of the erratic path of lightning will be found in Appendix A, No. 62, reported by Mr. W. Langdon, Past President, I.E.E.

APPENDIX A.

In the following tables will be found an analysis of reports selected from the L.R C. OBSERVERS' REPORTS on buildings which were furnished with CONDUCTORS* :—

The principal causes of the failure of the usual style of lightning rod as fitted on the buildings investigated, appear to be due to the following: (1) Insufficient number of conductor and earth connections; (2) the absence of any system of connecting the metallic portions of the buildings to the lightning conductor, especially the inter-connection of the finials, rain-water pipes, and gutters. The frequent damage by side-flash from the conductors might be lessened by running a horizontal conductor along the ridge, or along the parapets of all the roofs, somewhat after the method which is almost universally adopted in central Europe.

The lightning strokes may be divided into three classes: (1) Those where the conductor conveyed a portion of the flash to earth but the side-flash to other unearthed metallic conductors damaged the building; the practice of running the conductor round the projecting masonry, often taking sharp bends, doubtless facilitating the deviation of the current from its direct path to the earth. (2) In several observations a metallic roof of large area received the flash, consequently became highly charged, and the single conductor failed to convey the whole of the stroke, a portion of which took a circuitous path—for instance, through a speaking-tube and an electric bell wire. (3) A flash struck the building at two points simultaneously, a lightning conductor taking one part of the stroke, but damage was caused by the other portion selecting an unprotected part of the roof.

Earth Connections.—With a few exceptions, these had the defect common to nearly all earth-plates which are simply buried in the ground close to the foundations of a building, and owing to drainage soon became dry, consequently are of very high resistance.

Inter-connection with the Metal Work of a Building.—Although the utility of the external metal was specially put forward in the report of the Lightning Rod Conference in 1882, their recommendation has been apparently disregarded in all the cases under review.—AUTHOR.

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* The remarks were drawn up by Mr. J. Gavey, C.B., Engineer-in-Chief to the Post Office, and the Author. No. 74, column 4, should read "no conductor."

APPENDIX A.—ANALYSIS OF SE[...]

No.	Description of Building	Effect of Discharge on Building	Probabl[...]
1	DALSTON: German Lutheran Church.—Spire about 140 ft. high; nave, 80 ft. long and 40 ft. high *Reported by* Mr. George Legg	Fire, through ignition of gas at meter. Organ destroyed, and timbers of organ loft fired	From vane *vi*[...] pipe, lead flas[...] meter; thenc[...]
2	TRURO: Kea Church.—Wooden spire (88 ft. high) covered with copper *Reported by* Messrs. J. C. Daubuz and G. H. Fellowes Prynne	Tiling damaged; lead flashings turned back; wall considerably shaken and face stones fractured	Divided; part [...] part by alter[...] copper coverin[...] from which it [...] wall to lead fl[...]
3	STRADBROKE, NR. EYE: Church.—Square tower with lead roof, flagstaff, and pinnacles *Reported by* Mr. William Clutten	Flagstaff shattered; pinnacle badly damaged and had to be rebuilt; hole pierced in wall; door to turret thrown off	Passed from fla[...] door of turret, conductor
15	PORTSEA: Workhouse.-2-storied block of buildings *Reported by* Mr. George Cowan	Chimney and brickwork damaged; roof perforated; casing of electric-light wires splintered and wires fused	From chimney t[...] along iron pi[...] light wires
25	DARWEN: Alexandra Hotel.—Irregularly built *Reported by* Mr. F. G. Haworth, M.B., F. R. Met. Soc.	Chimney broken; grate displaced and marble fireplace broken down	Down the interi[...]
28	WALSALL: Shire Oak Brewery.—Chimney 70 ft. high *Reported by* Mr. G. H. Boulter.	Bricks displaced at top of chimney, and earth dislodged at bottom of conductor	Struck chimne[...] and then passe[...]
30	HAMPSTEAD, GOLDER'S GREEN: Convalescent Home, formerly private residence *Reported by* Mr. Walter Hall	Small hole made in apex of gable, casement of window damaged; plastering damaged and looking-glass smashed	Uncertain
38	WOOLWICH: No. 12 Magazine.—Copper roof *Communicated by* H.M. Inspector of Submarine Defences.	Uprights to fence or outer gate damaged	Struck fence; po[...]
41	LEADBURN: Signal Cabin.—Brick and wood *Reported by* Mr. James Wilson, and further by Mr. A. Clements, Superintendent of Telegraphs, N. Brit. Railway	Telegraph pole struck; train signalling instrument damaged; woodwork set on fire	From pole along[...]
54	STOERHEAD LIGHTHOUSE.—Metal roof and iron railing around lighthouse *Reported by* Mr. J. M. Irvine, Engineer	Wall damaged, bedstead scorched; gutta-percha wires of telephone circuit burned; woodwork set fire to	Part at least took [...] telephone wires[...] to wires; thenc[...]

...D REPORTS OF BUILDINGS STRUCK, WITH OBSERVATIONS BY THE COMMITTEE.

...Discharge	Character of Conductor	Conditions conducing to Discharge through Building			Remarks
		Insufficient Number of Conductors	Quality of Earth Connection	Alternative Paths of Discharge (unearthed)	
...uctor, rain-water ...nd gas-piping to ...th	Woven copper band (Spratt's), 3 oz. to the foot	—	Bad; only a few inches of conductor passed into gulley	Rain-water pipe, lead flashing. Rain-water pipe and gas-pipes not earthed or connected to conductor	Bad earth; neither lead flashing nor wat... pipes connected to earth though in clo... proximity to conductor; the lightning r... itself carried too close to the gas pipe... the gas meter not bridged over by a co... ductor joining the inlet and outlet pipes
... conductor and ...path formed by ...e, iron pipe, &c., ...through parapet	Copper tape $1\frac{1}{4}$ in. by $\frac{1}{8}$ in.	—	Good earth	Copper sheathing of spire, rain-water pipe, and copper wire which passed over conductor and near pipe	The rain water down pipes should have bee... connected with the roof metals, *i.e.* to th... copper roof and lead flashings, and al... to earth. This would have prevented th... side flash and consequent damage
...ong lead roof to ...through wall to	Copper rope $\frac{3}{8}$ in. dia.	Flagstaff being highest point should also have been protected	Very bad earth; rope merely knotted and passed through stone 18 in. below surface. Resistance to earth very high	—	Earth bad. The failure to provide a branc... conductor from the flagstaff to the mai... conductor, and the omission to earth th... lead flashing, real cause of damage
...roof and ceiling, ...ls to electric-	No conductor in part of building damaged	—	—	—	Insufficient number of conductors to prote... the whole range of buildings, and met... projections on roof not connected to eart...
... chimney itself	Copper rod (good quality) $\frac{3}{4}$ in. diameter	Formerly conductors on all chimneys; now only three	Character not stated	—	Insufficient number of conductors to prote... entire building; of the seven chimneys, a... of the same height, only three protected... the nearest conductor 41 ft. from the poi... struck. This is probably a good illustratio... of the B flash. At about the same tim... a horse was killed in a field outside th... town
...te conductor, ...luctor	Copper tape and rod carried 4 ft. above chimney	—	—	—	Building occupying the highest ground i... the neighbourhood. Illustrates fact th... lightning conductors on a shaft shoul... terminate at the upper extremity in mann... recommended by Committee
	Copper rope $\frac{1}{2}$ in. and $\frac{3}{8}$ in. diameter, and rod $\frac{3}{4}$ in. Three points	Only one finial point protected; three without conductors	Character not stated	—	All the finials should have been connect... by subsidiary conductors to earth
...nd broken	—	—	—	—	Magazine well protected against lightni... discharges; the damaged post so far fro... magazine that no protection afforded ... lightning rods. Probably a B flash
... cabin	Cabin not protected	—	—	—	Lightning protectors provided on all te... graph instruments. The one in questi... did not act efficiently
...peaking tube, ...by bedstead ...n at pole	Copper rod $\frac{3}{4}$ in. or $\frac{7}{8}$ in. diameter	—	Earth not good. Resistance from ground line 29 ohms	Iron railings; speaking-tube and telephone wires	An isolated building on an eminence ... copper speaking-tube and the iron rail... around the lighthouse should have b... connected to independent earths

APPENDIX A.—Analysis of Se

No.	Description of Building	Effect of Discharge on Building	
56	Devaar Lighthouse.—Iron lantern frame; copper dome, 130 ft. high; dwelling-houses 30 ft. from tower; lead roof and lead down pipes leading to enclosed cisterns or tanks *Reported by* Mr. C. Dick Peddie	Hole pierced in lead whistle-pipe; whistle and pipe fused, dwelling-houses near damaged; tank-covers weighing 28 lb. displaced 3 ft.	F
57	Rochdale: Stricklands Brewery. — Stone building, tall chimney, iron band round base of chimney *Reported by* Mr. H. Frost, Sectional Engineer, P. O. Telegraphs	Chimney cracked 15 ft. above shed abutting on stack; portion of rod above chimney broken off	U
60	Withernsea: Signal box, wooden cabin *Reported by* Mr. W. G. Cudworth, Engineer N. E. Railway	Window sash and frame of building fired. Block and bell instruments smashed and scattered in all directions	S
62	Blea Moor: Midland Railway line.—A guide post on footpath struck and charge entered wooden casing carrying cables, mounted on short creosoted pillars 12 in. above ballast *Reported by* Mr. W. Langdon	Guide post shivered into fragments. Boxing displaced and split open for a distance of 33 ft.	F
64	Cambridge: Cavendish Laboratory *Reported by* Mr. W. M. Fawcett, M.A., F.S.A.	Displaced tiles; made hole through sill of dormer and fused gas pipe	S
65	Maidenhead: Church of All Saints. *Reported by* Mr. Arthur Goulding.	Cock on finial of tower knocked off the spindle, breaking some tiles in its fall	F
66	Mark's Tey, St. Andrew's Church: Tower of oak; wooden spire covered with oak shingles *Reported by* Mr. W. Cressall	Displaced weathercock and disturbed some bricks	F
67	Possingworth House, Cross-in-Hand: Private dwelling *Reported by* Mr. Killingworth Hedges, M. Inst. C.E.	Building struck twice. First case struck and displaced conductor, and also did damage to chimney and slates. Second case destroyed chimney, damaged roof, and part of the divided flash struck statue not provided with rod	I

s Struck, with Observations by the Committee—*continued.*

	Character of Conductor	Conditions conducing to Discharge through Building			Remarks
		Insufficient Number of Conductors	Quality of Earth Connection	Alternate Paths of Discharge (unearthed)	
y e	Copper rod $\frac{3}{4}$ in. diameter. Forked finial	—	Two earth plates 20 in. by 10 in. by $1\frac{1}{8}$ in., 6 ft. apart, connected by rod. Soil not of the best	Whistle-pipes formed alternate path	Another case illustrating defect and 54; all metallic masses outside the tower should have connected and well earthed positions. Spires or towers w roofs should be provided with independent conductors, one on
	Rod with three prongs	—	Character of earth unknown	—	No sufficient data could be obtain of a definite opinion as to cause
t, ;	—	—	—	—	Somewhat similar case to 41. entered signal-box along teleg and the instrument-protector fa
d g e	—	—	—	—	An interesting case illustrating e chosen by lightning. A passag earth, up a wooden post, and in casing to reach the metallic s lead-covered cable, which it tr some distance before it enter chanical signal wire. This und circumstances would appear an route. The charge only reacl earth when it entered the rails
d f	Copper wire rope $\frac{3}{8}$ in. diameter on tower	Conductor on tower 36 ft. from point struck	Not stated, but the rod had been recently fixed	Brass knob to iron rod and lead cheek of dormer and gas pipe	Illustrates the need for earthing portions on the roof of a buildi
r	Finial rod $\frac{3}{8}$ in. iron 6 ft. above apex of spire; $\frac{1}{2}$ in. wire rope	—	Stated no earth plate	—	The cock formed an imperfect minal to the lightning rod; this the rod acted efficiently
d -	Copper wire rope, $\frac{1}{2}$ in. diameter; single pointed terminal	—	Not stated	—	Beyond displacing weathercock a few bricks where the rod e ground, no damage done; alth rently not efficiently terminate end the rod conveyed the char earth
y n ', - - n	Copper tape, $1\frac{1}{8}$ in.	Everychimney-stack fitted with a rod. The flash struck the rods on both occasions about 3 feet below the air terminal	Good.	The tape conductor was run indirectly to earth, so that a portion of the charge travelled down the wet roof	These two cases can only be explained on the supposition th charges were of the B type hypothesis is supported by th numerous trees in the neighbou struck. An unusual number c rods were provided, although th interconnected. It will be not structure did not suffer a damage, so that the rods aff measure of protection; and if th connected by a horizontal con nished with more direct earth con damage might possibly not hav

No.	Description of Building	Effect of Discharge on Building	
68	ST. PANCRAS' CHURCH, EUSTON: Spire surmounted by gun-metal cross. Lead roof *Reported by* Mr. Arthur R. Kelly	Gas-pipe fused and gas ignited in church; joints in buried gas-pipe parallel to and 16 ft. from buried end of conductor destroyed; large escapes of gas caused; electric light fuses destroyed	Portion exhaus supply
73	SWANSCOMBE: Church, with oak shingled spire *Reported by* Mr. W. P. Goulding	Fire; portion of church destroyed	Along r 5 ft. ab to eart inside. fire
74	ALDENHAM Church, near Watford, Herts.—Timber spire on top of tower. Clock chamber some 20 ft. below lead flat of tower; clock weight exposed through belfry, but below belfry cased in down to floor of church, where there is a pit 6 ft. deep to receive it *Independent reports* by Messrs. Harry G. Assiter and Fred. V. Selfe	Copper weathercock twisted; oak timbers and shingles of spire shattered; wood casing for clock weights, and oily rags at base thereof, ignited	From lea bell; th steel clock w
75	ST. BOTOLPH'S, ALDGATE: Church with tower and spire *Reported by* Mr. Killingworth Hedges, M.Inst. C.E.	Parapet under spire shattered. Finial to which conductor connected disturbed at base	
76	KINGSTON: Boys' School.—200 ft. by 50 ft. 60 ft. to ridge of roof *Reported by* Mr. Isaac Slade	Chimney stack damaged. Picture hung with wire scorched	From course ing
78	INVERNESS: Post Office.—Standard overtopped mansard roof by 12 ft., and had 15 wires attached to it. Flat tops of mansard roofs covered with sheet lead *Reported by* Mr. J. M. Irvine, Engineer P.O. Telegraphs	Lead on roof damaged. Below roof two discarded gutta-percha covered wires (reaching from ceiling to within a foot of iron hot-water pipes on floor) set fire to, and wood lining of rooms ignited	
79	BENEFIELD: Church with tower and spire surmounted by a copper cross *Reported by* Mr. Fred V. Selfe	Displacement and bulging of spire, threatening its collapse; supposed to have been caused by lightning. No direct evidence	From c suppor throug ductor

BUILDINGS STRUCK, WITH OBSERVATIONS BY THE COMMITTEE—*continued.*

	Character of Conductor	Conditions conducing to Discharge through Building: Insufficient Number of Conductors	Quality of Earth Connection	Alternative Paths of Discharge (unearthed)	Remarks
steam or and	Copper stranded cable $\frac{5}{8}$ in. diameter looped round square base of gun-metal cross on top of spire, then to lead roof and to earth	—	—	Alternative path formed by relief pipe (which protruded above roof) hot-water system, and finally to earth *viâ* gas-pipes	Most interesting and instructive case. lightning charge evidently struck the and set up violent electrical oscillation the lead roof with which it was in meta contact at one end. Had suitable ea connections been provided at the dist end of the nave, and had the heat system been also connected to earth, damage would have occurred. The c outlet to earth for the charge was the gas-pipe; hence the damage
about n rods iannel set on	$\frac{3}{4}$ in. solid iron rod in 10 ft. lengths united by plumber's joints; ended 2 ft. above earth on iron gas barrel, but (said to be) not connected	—	Rod ended in an iron tube which entered ground. Earth very bad	—	An imperfect rod with very bad ea Apparently the charge entered the to at the lower opening and found its to earth, setting fire to the staircase in passage
tenor vn the n.) of	Copper cable, 1 in. diameter; connected to finial		Not stated	—	An interesting case in which the meta bell-cord acted as a lightning rod, dam being restricted to the upper and lo extremities only
	—	—	—	—	The lightning rod took several sharp ang that may have caused side flash, wh reporter thinks passed on to earth *via* rain-water pipe, which was near but connected to the rod
llowed build-	Not stated	Insufficient number of conductors	Not stated	Conductor followed side of iron down pipe; distance between not stated	Damage probably due to two causes: fi a single lightning rod of moderate hei quite insufficient to afford reasonable p tection even against A flashes; a secondly, the interior pipes for heating a other purposes formed an alternative p which could only be reached by a fract of some part of the structure
	One conductor, $\frac{7}{16}$ in. strand, copper, 12 ft. above roof fastened with galvanised iron staples. Wires at top were untwisted, separated, and sharpened at points; at bottom were soldered to 12-in. iron water-main pipe, after encircling it several times	—	—	—	The damage was probably duc to the that the lead flats and the iron porti of the building were not connected earth
pright then con-	Not stated	—	Said to be faulty	From copper cross and upright to cross beams supporting same	A case in which upper portion of spire fo to be damaged in a manner which might l occurred had a lightning flash followed course of the copper cross with its met support, then flashed through stonewor the conductor. Indirect evidence only

APPENDIX A.—Analysis of S

No.	Description of Building	Effect of Discharge on Building	
80	Welbeck Abbey: Library and chapel.—Rectangular building—copper-covered roof *Reported by* Mr. J. Wallace Stevens	Window sill broken and pieces thrown about; rain-water pipe (sunk in wall) bared	Un w
83	Highgate: St. Michael's Church.—Tower and spire surmounted by stone cross, 145 ft. high *Reported by* Mr. Walter Hall and Mr. Killingworth Hedges	One arm of stone finial cross broken and displaced; ball of cross shattered; falling stones crashed through roof of nave	Str p
85	Derby: Carriage sheds.—Midland railway *Reported by* Mr. W. Langdon	Shed itself unhurt, but discharge struck gas-pipe on roof of carriage and ignited gas	Un
86	Bolton: Ainsworth Mill.—Chimney about 60 ft. high *Reported by* Mr. W. W. Midgley, F. R. Met. Soc.	Chimney demolished. Windows of mill broken; gas-pipe fused and gas ignited. Engine-house destroyed by falling chimney	No
88	Bedford: St. Paul's Church.—Tower and spire *Reported by* Mr. W. P. Goulding	Heavy beams inside building slightly displaced, supporting corbels split; main switch of electric light fused. Iron rain-water pipes broken; lead flashings on roof broken and torn away	By f c f p
93	Coatbridge, Lanarkshire: Church.—Tower about 80 ft. high, upper half octagonal, carrying eight cone-shaped balusters, one at junction of each angle *Reported by* Mr. W. E. A. Knight	Three balusters damaged and part of conductor rod led round tower fused. Roof damaged by falling stones	St p v
94	Torr Head: Coast Guard Station *Reported by* Mr. T. Patterson, P. O. Engineer	All windows smashed; iron eaves gutter smashed; telephone wires fused	N
97	Canton, Cardiff: St. John's Church.—From top of steeple to ground, about 175 ft. *Reported by* Mr. W. H. Monk, P.O. Telegraph Superintendent	Conductor torn away at about 30 ft. from the trident; electric-light wire fused; plaster damaged in several places; lead on lower roof ripped up; and stone coping torn away where lightning left conductor for the leads	A
98	East London Waterworks: Chimney of Pumping Station, Sunbury. *Reported by* Mr. W. B. Bryan, M.Inst.C.E., Chief Engineer	Struck upper cornice of campanile, then lower cornice, shattering stonework above and below	F

UILDINGS STRUCK, WITH OBSERVATIONS BY THE COMMITTEE—*continued.*

	Character of Conductor	Conditions conducing to Discharge through Building			Remarks
		Insufficient Number of Conductors	Quality of Earth Connection	Alternative Paths of Discharge (unearthed)	
to rain-	Two conductors, copper wire twisted $\frac{1}{2}$ in. diameter	—	Earth connections bad (Details unknown)	—	Damage insignificant, probabl oscillatory side flash from the to the rain-water down pipes not in metallic connection
robably	Copper rod, $\frac{5}{8}$ in. diameter	—	Found to be in connection with the electric-light mains	—	A stroke caused similar damage ago
	—	—	—	—	One of fourteen railway carriage in a light timber shed unprov conductor
	Not known, but said not to be in good repair	—	Unknown	—	The fall of the chimney wrecked house, and the mass of débı great as to prevent further in The flash would appear to ha path along the interior of the preference to that furnished b lightning rod, for it burst out structive violence at the ba chimney, causing the collapse of
to lead which portion in-water	Copper cable $\frac{5}{8}$ in. diameter terminated under seat of weathercock. From the base of the spire the conductor was laid on the lead flat	—	Not stated	Formed by lead roof and rain pipes &c.	A very interesting case. The being in contact with the lead oscillations were set up whicl the whole length of the roof; no conductors being provided, the took all available paths, some some outside the building
circular then to h	Copper rope of seven strands from above balusters to earth. A subsidiary conductor carried around at the base of the balusters and connected to main rod	—	—	—	A conductor on each baluster rea to the circular band at the b balusters would have prevented
	Building itself not protected. Flagstaff which is apart from but close to the building protected by conductor $\frac{1}{4}$ in. diameter	—	Earth bad; conductor buried in cement	—	Had a good earth been provid conductor on the flagpost pro damage would not have occurred
along ic-light heating	One conductor; trident at top, and about 12 ft. of iron casing at bottom	—	Bad. Earth plate 1 in. wide, and about a yard long, buried about 10 in. beneath surface in very dry soil	—	The lightning rod very old and thin where it passed through t conductor fused and main char to the lead flashing of the lower shows the necessity of running earth and avoiding sharp bends
scaping upper stand-	No special conductor, as the 36-in. steel standpipe connected to several miles of mains came almost to the top of chimney	—	Raining heavily	—	This proves that a flash will follov of hot air, and in this case w from the standpipe which forme conductor to earth

CHAPTER VIII.

INSURANCE COMPANIES.—TREES AND LIGHTNING STROKE.

INSURANCE against damage by lightning is now included in most policies, and it would be imagined that the companies would reduce the risk as much as possible by recommending the protection of buildings, or at any rate see that an efficient lightning conductor is installed after an insured building has been struck. There are many instances of churches being struck more than once, but they remain unprotected. Godshill Church, Isle of Wight has suffered by three strokes (see page 74), but up to the time the L.R.C. observer made his last report, nothing had been done in view of the possibility of a fourth stroke.

The insurance offices do not seem to care whether a building is protected or not, as no individual office likes to insist on the erection of lightning conductors for fear of diverting business to its rivals.

The amount of damage to property by lightning stroke is enormous; most people think that almost every church has a conductor, whereas not 10 per cent. are so provided, in fact, although there is sometimes a recommendation from the archdeacon that the churchwarden should put up a conductor and see that it is kept in order, if the vicar wishes to safeguard his church the cost usually has to come out of his own pocket.

The present attitude of insurance companies is somewhat similar to that following the introduction of electric light; at first, as regards wiring, it was go as you please, but the frequent electrical fires roused the companies, who, borrowing advice from the United States, began one by one to draw up rules, until at the present time almost every company of importance has its electrical inspector.

In Michigan, U.S.A., the number of cases of damage by lightning stroke reported to the Commissioner of Insurance in 1895 was 316, covering damages amounting to $37,563, in the following year the number of cases rose to 1,509, and the damages to $143,841. This increase might be abnormal, and in making statistics one must compare the average of a certain number of years with the average of a similar number of preceding years. The most comprehensive statistics for the study of secular variation in damaging lightning strokes are those of the German Empire. Dr. Wm. von Bezold as early as 1869, in a study of the statistics collected by insurance associations in Bavaria, expressed the opinion that there was a steady increase in danger from damaging lightning strokes. He again took up the subject in 1874 and in 1884, finding in both cases a continuation of the increase first noted in 1869. Mr. Kasner confirms the increase for the province of Saxony and the Duchy of Anhalt. "In the flat country there were 804 cases of damaging stroke for the five years 1887 to 1891, as against 1,088 in the five years from 1893 to 1897, an increase of 35·3 per cent." He also shows that the danger from lightning in the country is nearly four times as great as in the cities.

In Schleswig-Holstein some of the insurance companies bear a part of the expense of fitting conductors to buildings insured by them. The East Prussian Fire Insurance Company bears half the cost; others make a reduction in the annual premium. The former course is preferable, as being more attractive than an annual reduction; it is more convenient to the house owner to pay a slightly higher premium each year, than to disburse at a given moment the whole cost of installation. In Holland the total sum paid out by the larger Dutch companies for losses through fire was in 1905, £1,343,750, of which £84,333, or 6·28 per cent., was due to lightning. In Schleswig-Holstein the following reductions are made :—

For slated or tiled houses ...	... 5 per cent.	For thatched houses	20 per cent.
For schools	... 10 " "	" windmills	... 20 " "
		" churches	... 50 " "

TREES AND LIGHTNING STROKE.

Whether forest trees act preventively, like a multitude of lightning conductors, is an open question. In the report of the Lightning Rod Conference, 1882, ashes, elms, oaks, and poplars are called dangerous; beeches, birches, and maples are mentioned as

hardly ever touched by lightning, and this view was brought forward by Mr. Hugh Maxwell, of Massachusetts, as long ago as 1787. A very elaborate investigation of the underlying causes of the seeming preference of lightning for certain trees was made by Mr. D. Jonesco,* in Stuttgart. He laid aside, as having little or no influence, such physical conditions as the characters of the soil, whether dry or moist, and the depth to which the roots penetrate. His observations seemed to show that trees are liable to be struck when starch-producing and not when fat-producing—as oaks, willows, poplars produce hardly any oil, others, lime trees and firs, according to the season, oil or fat. The wood of those trees rich in fatty material was in all cases a poor conductor of electricity; on the contrary, the trees rich in starchy materials conducted electricity very well, and no important differences were noted for the various kinds of wood. Poplars have been studied, and it has been proposed to utilise them as lightning rods, by providing them with iron belts and earth plates. According to Hess,† when the branches come nearly to the ground, and where the soil is damp, they would be useful in protecting a building. The following is a Table prepared by the Dutch Meteorological Institution of the strokes on various trees between 1885 and 1902:—

Poplars	232	times.	Walnut	8	times.
Oaks	130	,,	Beech	5	,,
Willow	70	,,	Chestnut	5	,,
Yew	50	,,	Apple tree	5	,,
Firs	27	,,	Cherry	4	,,
Pear tree	25	,,	Alder	4	,,
Oak	18	,,	Birch	2	,,
Lime	14	,,			

"The German Government caused, in 1899, an enquiry to be made into the subject of lightning and its effect upon trees, the observations having been entrusted to the overseers of nine foresting stations scattered throughout an area of nearly 50 thousand acres in the district of Lippe. It was found that of all forest trees the oak was most susceptible to the attacks of lightning. The forests were found to comprise various kinds of trees in the following proportions: beech, 70 per cent.; oak, 11 per cent.; pine, 13 per cent.; and fir, 6 per cent.; of the 275 trees which suffered

* "Ursachen den Blitzschläge in Bäume." Stuttgart, 1892.

† Elektro. Zeitschrift, 1900.

from lightning during a period of several years, no fewer than 58 per cent. were oaks, 21 per cent. firs, 8 per cent. beeches, and 7 per cent. pines. There were 6 per cent. of other kinds of trees."

"It is noteworthy it has been stated by some English authorities that the beech is seldom or never struck by lightning. The truth of this statement has long been disproved, and it is interesting to see that the beech in Germany appears to be more often the subject of lightning stroke than the pine."—*Chambers' Journal*, 1900.

The following is an extract from Captain Maclean's paper on the Action of Lightning, 1890. "The injury to trees are of two kinds; the first, far the most common, is simply to score out the bark up the trunk of the tree, out along one limb and, then, perhaps, the marks are seen on two or three of the upper branches to the outer twigs. In some cases the whole of the bark on one side is blown off as well. The rain is falling, and one or more streams of water are running down the sides of a tree, forming a conductor which becomes insufficient at the time of the discharge to carry off all the electricity, and therefore it becomes so suddenly converted into steam as to blow out the bark along the line; and if there is any communication with the sap by knot-hole or other flaw, the sap is also converted into steam and the bark blown off. The other form is the shattering of the tree, which I imagine to occur when the electricity is insufficiently carried off by the outer surface, and collects at the junction of some main branch with either the stem or with some other branch, where there is, perhaps, a cavity with water in it, or a collection of moist dead leaves, the tree is then easily rent by the explosion of steam generated. If the tension be very great, and especially if the air round the tree be dry, the sap may be violently exploded, and the trunk splintered and shattered as if by dynamite. Of the trees examined, the only ones shattered were those struck before the rain fell, the others were scored simply, with bark blown off."

THE EFFECTS OF LIGHTNING ON MANKIND.

There are few natural phenomena which make so deep an impression on mankind as thunder and lightning. Although we have ceased wondering at the developments of electricity—which is successfully harnessed as a rival to steam for the propulsion of trains, and companies vie with one another for the right to distribute electrical power at a pressure which would be extremely dangerous unless under proper control—a thunderstorm is considered a far more serious matter, and many instinctively dread it, knowing that there is a chance, perhaps very remote, of their being struck; besides, every storm entails a real danger to property. To a large extent the feeling is the relic of the superstitions of our forefathers, who regarded lightning as the direct manifestation of the wrath of some offended deity. In the time of the Romans, persons killed by lightning were considered to be hateful to the gods, and were buried by themselves, lest the ashes of other men should receive pollution from them. It is curious to note that at the present time the same buildings are occasionally again and again struck, and that certain localities are visited by thunderstorms more than others; a fact which has been taken advantage of by the witch-doctors in South Africa, who are said to stand fearlessly in a certain spot during a terrific storm, whereas in the vicinity it would probably be very dangerous to do so, because the large amount of minerals in the rocks might divert the lightning. The superstition of the ancients may appear in this twentieth century to be extremely ridiculous to us; but we should not overlook the fact that when Benjamin Franklin—whose memory has been honoured by the erection of a statue in Paris on the two hundredth anniversary of his birthday—introduced the lightning-conductor, for many years his invention was opposed on the plea that "it was as impious to erect rods to ward off Heaven's lightnings as for a child to ward off the chastening-rod of its father."

* "Even to-day the brilliancy of lightning hides itself from us in the darkness of impenetrable mystery, but we feel that there is an immeasurable power and unimaginable force which rules us. In increasing our observations and in comparing those which are analogous, we may hope if not to arrive at an immediate conclusion

* "Thunder and Lightning"—FLAMMARION.

INTERIOR OF BARHAM CHURCH, STRUCK FEB. 8, 1906.

at least to help on the work of discovering what laws govern this subtle and imponderable fluid.

"Here it will strike a man dead without leaving a trace; there it will only attack the clothes and insinuate itself as far as the skin without grazing it. It will burn the lining of a garment and leave the material of which it is made intact. Sometimes it profits by the bewilderment caused by its dazzling light, to entirely undress a person and leave him naked and inanimate, but with no external wound, not even a scratch.

"It would seem as if lightning were a subtle being. We see it twisting into space moving with astonishing dexterity among men, appearing and disappearing with the rapidity . . . of lightning . . . it is impossible to define its nature. At all events, it is a great mistake to trifle with it. It means running great risks."

The indiscretion of Dr. Richmann in 1753 may be quoted as an example. He had fixed an iron rod to the roof of his laboratory and was accustomed to measure the intensity of the electricity, but during a thunderstorm approached too closely to the conductors and was immediately struck dead.

Barham Church illustrates the way in which a flash, of probably the B type,* behaves inside a building—fortunately on this occasion without loss of life. The worshippers at the Cathedral of Avila, Spain, were not so fortunate. It is reported that in May, 1909, the lightning stroke killed the officiating priest and three ladies at the altar, which was set on fire.

At Barham the lightning struck the church on either side of the gable cross at the east end, and entered in two places. The tower, which had a small flêche, upon it, was untouched, and so were the numerous tall elms and limes round and in the churchyard. One stroke passed down and through the east window, breaking the stonework and shattering the altar top, a slab of marble six inches thick; it wrecked the marble steps, and escaped by the hot water pipes, which were for some yards broken to pieces. The other part of the same flash took a more zig-zag direction, entering the church by the sill of the window and coming out through the wall, forcing its way through the marble pavement and making a small hole near the hot water apparatus.

The subtleties of lightning are so inexplicable and its visitations are so numerous that it is impossible to describe the many fatal and

*Page 9.

serious accidents which yearly take place, and the question naturally arises

WHERE TO SEEK SAFETY DURING A STORM.

The first and principal rule to observe is not to get under a tree, or even stand near the lateral branches. Even if a small portion of the flash should travel over the wet leaves, a person underneath would form a convenient path for the lightning to pass to earth.

It is equally dangerous to take shelter alongside a building or close to a hay stack, for a similar reason, as the rain dripping off the roof may lead the flash in the direction where one is standing. Several

EFFECTS OF LIGHTNING ON THE CHAPEL, THIRSK.

accidents have also occurred to persons who have entered unfinished houses, where the scaffold poles have acted as conductors.

The path taken by a lightning stroke is shown by the illustration of the Chapel at Thirsk. It will be seen that although the ventilator on the roof was struck, a portion of the flash jumped to the rain water pipe and part descended from the rain water gutter at points where it overflowed. The photograph is also interesting as showing there was no protection from the lofty spire of the church, which was quite close and was not struck.

A wide berth should be given to telegraph posts, and the telephone should never be used during a violent storm. Do not stand near any rain water or ventilating pipes, and keep away from lightning conductors.

Trees act to a certain extent as lightning rods, so that anyone is fairly secure in their neighbourhood—safer, in fact, than on a treeless plain. Probably if the traveller is getting very wet it is best to take shelter under a hedge or in a low copse, but on a moor or common the wisest plan is to lie down during the height of the storm. Under no circumstances should a bicycle be ridden or led, nor should an umbrella, or long fishing rod be held up. It is not that the lightning is directly attracted by such objects, but a flash on its way to earth gives out innumerable smaller discharges, so that to be near any objects containing metal, or one that projects into the air which may be selected as offering the best path, is, to say the least, unwise, as it should be remembered that a shock which may only cause minor injuries if one's clothes were dry, might prove fatal to a person who has been some time out in the rain.

The safest place is undoubtedly inside a house. It is remarkable that although there were many injuries and marvellous escapes, there were only two serious accidents among the 115 cases of buildings struck which were sent in by the observers to the Lightning Research Committee, 1901-1904.

The following suggestions may be made: Keep away as far as possible from the fire place, as if the chimney is struck the grate and surroundings will almost invariably be blown out into the room.

Hot water pipes are very likely to be selected, and they should be avoided during a storm; also do not sit in a greenhouse or a conservatory, as a portion of a flash may pass down the training wires and other metal work, and do not take shelter in a farm building where animals are collected. The idea that glass attracts lightning is absurd, and if one does not mind the glare of the lightning there is no evidence to show that it is unsafe to approach the windows; it is better, however, to keep them shut.

TO RESTORE CONSCIOUSNESS IN THE CASE OF A PERSON STRUCK BY LIGHTNING.

1. Make the subject breathe by artificially imitating the respiratory movements of the chest.
2. Keep the body warm.
3. Send for a doctor.

Of the visible effects of lightning stroke upon the human body little more can be said than that sometimes burns, usually superficial, have been noticed. Frequently red lines or markings are noticed

which are probably localized conjestions of the small blood vessels of the skin. These, from their irregularities and branchings, have led to the fanciful idea of photographs of trees, etc.

It may be said that lightning frequently causes a temporary paralysis of the respiratory organs and heart, which if left alone will deepen into death, but intelligently treated, will generally result in recovery.

UPWARD DISCHARGES OF LIGHTNING.

As a rule we imagine that lightning always descends, that it comes from the higher celestial regions to be lost in the common reservoir, but this is not always the case, sometimes it re-ascends; that is to say, after it reaches the ground it travels through the earth to a point where the resistance of the air is less than from where it descended and again escapes to a cloud. The illustration shows a downward discharge taking place at one point and a corresponding upward discharge is shown at some distance away.

There are instances of people being seriously injured by a reverse stroke, and in some parts of South Africa the shocks from the ground are very severe. The engineer of the railway which was being constructed near Fourteen Streams told the author "that the Kaffirs sometimes knocked off work, as they could not handle the rails, which were highly charged, although no lightning was visible."

The upward stroke of lightning has been noticed by Professor Platania after a storm in September, 1906, which caused much damage to the Florini Palace, near Catania, Sicily, recently fitted with a complete system of lightning conductors. It appeared that the upper terminals had not received the flash, but that the direction of the discharge was from the positive electricity of the ground to the negative of the clouds. Doctor Folgherarter found

in the Roman Campagna six cases which showed an upward stroke, and *Professor Max Toepler, in his paper "On the Direction of Electric Streams in Lightning," describes twenty-nine cases of direct and thirty-three reverse strokes. The author noticed that a slight crater was formed in the ground where an upward stroke had taken place during a violent storm near Colorado Springs, U.S.A.

LIGHTNING ON THE HIGH ALPS.

Messrs. Hutchinson and Ward, of Oxford, had some interesting experiences when they stayed at the Margherita Hut on Monte Rosa for a period of eight days in August, 1907, for the purpose of investigating human respiration at an altitude of 15,000 feet, on behalf of the Royal Society. When a thunderstorm took place and the cloud was below the hut gorgeous brush discharges pointing downwards took place from pieces of wood on the roof, but when the cloud rose above the hut the discharges were upwards; a frozen piece of paper also gave out a luminous discharge. They also experienced the effect of actually being in a storm-cloud.

Mr. Hutchinson's account is as follows: "First it hailed very hard, round hailstones just half-an-inch in diameter, then the lightning fell all round and very frequently on the hut, which was completely coated with copper and furnished with bunches of spikes in prominent places—the structure is held down by cables which are fixed to the copper. All we could see was a rather pale flash, very dazzling, the roof hissing as it was struck, but we felt no shock whatever. We decided to help a party who were coming up the mountain, as soon as I stepped outside the door I felt half dazed, and it took me a few seconds to realise what was happening. I was conscious of a violent pricking in my head as of lots of needles, only less painful. Our ice axes were discharging electricity and hissing hard, and so was the hut and most of the neighbouring rocks; it was unsafe to lift one's arm or even a finger, as a sharp pain was felt in it at once, and as each lightning stroke fell on the hut, which was not 100 yards from us, we got a pretty violent shock, which made us start and catch our breath, but otherwise did no harm. We carefully held our axes by the middle of the wood, but one of the party when five yards from the hut leaned on his axe, and was immediately knocked down, so we left our axes, and on entering the hut again felt nothing, which was a more conclusive

*"Meteors," Zeitschr., 1901.

proof of the protective effect of the copper sheathing than any of Faraday's well known experiments."

THE MAGNETIC EFFECTS OF LIGHTNING.

* Professor Platania also made some interesting experiments in 1906, and noted strong magnetic effects where lightning had struck some houses near Catania constructed of lava blocks from Etna and of brick. In one observation the fragments of a telephone wire of galvanised iron which had been struck acquired magnetic polarity; for instance, taking a piece of wire fused at one end and cut at the other, the latter attracted almost equally the north and south poles of the needle, while the fused end if placed near the north pole pushed it back 5 degrees; another piece fused at both ends caused the needle to deviate 20 degrees. The earth wire of the telephone ran down the face of a wall, and strong magnetic polarity was shown by the compass when it was held about six inches from the wall, the needle swinging right round. In another observation, although he did not find the wall so affected, at a distance of four yards from the conductor there was sensible deviation of the magnetic needle.

One of the most common effects of lightning on watches is the magnetisation to which the various pieces of steel are subjected. In one case the balance had its poles so well defined, that when placed on a piece of wood and floated in water, it acted in a similar manner to a compass needle.

The author mentions at page 36 that he had also found iron in a building which had been struck to have been partially magnetised.

*Memorie della Classe di Scienza Academia degli Zelanti, Vol. IV.

CHAPTER IX.

FULGURITES AND OTHER VAGARIES OF LIGHTNING. SUNDRY NOTES.

FULGURITES, lightning tubes, or ceraunic sinters (Fr. fulgurites, pierres foudroyées; Ger. Fulguriten, Blitzröhren, Blitzsinter), as their name implies, are fused tubes or other fused structures, produced in sand, earth, or in rocks, by the action of lightning. They seem to have been first noticed by Pastor Hermann, of Massel, Silesia, in 1711, who, however, erred as to their origin, since he considered them a kind of fossil. It was, notwithstanding, early known that lightning causes fusion, as the papers of de Fischer, Buchholz, Tillet and Desmarest, and Alleon Dulae indicate; and, in his papers on lightning and lightning conductors, Reimarus mentions that the points of conductors occasionally melted during storms. In his Alpine travels between 1768 and 1789, Saussure found small blackish beads on the face of some slaty hornblende on the Dome de Gouté, obviously produced by the action of lightning.

The directness of the evidence as to the origin of fulgurites is, perhaps, best illustrated in the account given by Withering in 1790, published in the Phil. Trans. of the Royal Society. On 3rd September, 1789, a tree was struck by lightning and a man who had taken refuge thereunder was killed. At the point of his walking-stick a perforation, 2½ inches in diameter and 5 inches in depth, marked the place where the flash entered the ground. On digging, the soil was observed to be blackened for 10 inches more; 2 inches deeper again melted quartzose appeared, and continued in a sloping direction for 18 inches, the fused material having run down the tube formed.

"The fulgurites from the Kensington sandhills, New South Wales, present no new feature as regards their form or general character. Externally they are rough, somewhat whiter than the surrounding sand; inside they are enamel-like, from the glassy surface of the fused silica. Under the microscope the fused material is seen to be full of small vesicles; the surrounding sand fused in the oxyhydrogen jet presents an almost identical appearance. In chemical composition the fulgurites are substantially the same as the surrounding sand.

FIG. 73.

"Unfortunately, too great a mass of sand would have had to be moved to reach the terminals of the tubes. After following one for a length of 10 feet along its course, there appeared no indication of a change in size, and further excavation was impracticable."—J. W. Grimshaw, M.I.C.E.

The photograph, Fig. 73, exact size, gives a definite idea of the appearance and characteristics of fulgurites formed in loose sand.

The Brighton Seashore Electric Railway. Magnus Volk, M.I.E.E., 1900.—The overhead wire was struck some distance away from the car, the current went to earth by the trolley pole of the car, and opened a 200 ampere automatic switch at end of the line with a loud explosion.

At **Labuan, Borneo,** a doctor was dining, when a flash on the roof jumped to the lamp and thence to table, through the table

cloth and table down to earth. The cruet was fused, also knives and spoons. There was no appearance of any burning.

Side flash from a tree, Stilland Farm, Shillinglee, Sussex, January, 1904. Observer: Admiral J. P. Maclear.—Poplar tree was struck about 25 feet from the farmhouse, and at the same time the angle of roof received a stroke which passed down the rain-water pipe and portion of the discharge entered the lower room, passing by a moulding which was covered with gold leaf; much glass broken, front door forced open inwards.

NOTE.—The tree acted as a conductor, and the oscillatory discharge affected the building.

Upward effect of lightning, Garthersburg, Mo., U.S.A., June, 1902. Observer: S. A. Lehman.—Oak tree about 30 feet from house; piece about 70 feet long, weighing about 70 lbs., was thrown *upwards* at an angle of 35 degrees through the house. No marks on tree above place where slab was torn off; house not struck.

Inductive condenser discharge, June, 1894.—Several men were working in the United States Navy Yard at Norfolk, and during a storm had taken shelter under the iron hull of the *Raleigh*. There was no flash of lightning, and the officers on deck felt nothing, but the men were killed.

Linesman upon the telegraph wires at Shrewsbury was fearfully hurt on a fine evening by a storm raging 50 miles away at Hereford.—C. E. Spagnolletti, M.I.E.E., 1890. A similar case was reported from Russia in 1894; the storm was 70 miles distant.

Lightning strikes a railway carriage, July, 1900. Observer: W. Langdon, Past President, Institution Electrical Engineers.—The carriage was standing in a light timber shed at Derby, having some twelves lines of rails running through it; it was standing on the second line from the wall which forms one side of the shed, and was one of fourteen. All the carriages are alike and are fitted with gas, having a gas pipe nearly the whole length of the top of each leading down to a gas reservoir fixed under the framework. The stroke, which showed no trace of passing through the shed, struck the gas pipe on the top of the carriage, made a clear hole of about $\frac{1}{4}$ inch diameter in the pipe, and ignited the gas.

NOTE.—This was probably a side flash of great intensity from a B discharge to the adjoining rails outside the shed. It must have passed through the shed, but made such a small hole that it would be difficult to locate it.

A barn filled with hay was struck, but instead of the flash passing outside it went to earth through the hay, burning a large hole all the way down.—Paisley, Canada, 1902.

Curious freaks, New York, August, 1904—The flagstaffs on the Post Office, Tammany Hall, and the Flat Iron building, were struck, splintered, and hurled in fragments into the streets. Long flashes of lightning played from the rails of the Elevated Railway, and some woodwork was ignited. See page 82.

Myrthyr Tydfil Waterworks. Cracking of cast iron plates. Observer: George F. Deacon, M.I.C.E.—In the dam used for impounding water was a vertical recess 50 feet long by 5 feet wide. The face was closed by ribbed cast-iron plates about $\frac{3}{4}$ inch in thickness, see Fig. 74. The plates were loose in the brickwork, and the pressure of water was equal on both sides. In December, 1902, the water was drawn down, when the whole of the plates for 33 feet from the bottom were found to be cracked. The highest valve plate, shown by line on Fig. 74, was star cracked, and from out of the crack on this plate the main crack passed for 30 feet downwards through all the plates and flanges, and several large masses had fallen away. The iron was tested by Professor Unwin

Fig. 74.

and found to be above the average strength. A thunderstorm was recorded at the works about the time the accident probably occurred; the tower above was not then fitted with a lightning conductor. The case was submitted to Sir Oliver Lodge, who reported as follows :—

"I do not think the hypothesis of a lightning shock is utenable. A spark taking place under water breaks it or throws it asunder with great violence, producing a real explosion, so that even a small spark under water can shatter an open tumbler in which the water is, and I have strained a copper vessel by taking sparks inside it when full of water. I think, therefore, that a flash of lightning taking earth through water would be quite competent to smash the iron in the way described."

Explosion of a sugar boiler at Liverpool. Observer: Sir Oliver Lodge, F.R.S.—A syrup boiler exploded, killing a workman. A pipe from the roof entered the boilers through a fairly insulated washer into the interior, and dipped below the liquid nearly down to the bottom of the vessel. It was thought that lightning entering the pipe from the roof produced the explosion.

New York, August, 1904.—During a storm a steel chimney of the Smith Varnish Works on Long Island was struck and a tank of varnish exploded. The works were destroyed.

SUNDRY NOTES ON LIGHTNING.

Explosive action of Lightning, R. A. West, *Nature*, November, 1903.—" A cedar tree, 50 feet high, stood at a distance considerably less than its own height from a house at Englefield Green. The tree was struck, about 15 feet of the top was broken off, and the main portion of the trunk to about 4 feet from the ground was split in two. At the same time, an auracaria about 30 feet from the cedar was beaten down by a flash accompanied by much noise like pistol cracks, and a cloud of steam rose from the lawn on which the trees stood."

NOTE.—It is probable that what was seen in the auracaria was the reflection of the flash that struck the cedar, and the steam emanated from the cedar, which was said to be of vigorous growth and full of sap. There is nothing to indicate an explosive effect in this case.—AUTHOR.

" **Balloon** on leaving earth ceases to be charged electrically, as if a small portion of the earth."—*Standard*, 1900.

Captive balloon struck at Augsburg, at an altitude of about 1,000 feet. Aeronaut saved, but men holding rope were rendered unconscious.—1902.

Bell-ringing and storms.—"The poor believe that this pious exercise dispersed the evil spirits of the storm, while the better sort said that it caused some kind of undulation in the air and broke the continuity of the electric fluid."—"Edward's Untrodden Peaks, &c.," Routledge, 1893.

The following monkish rhyme was inscribed on mediæval bells.—"Funera plango, Fulgura frango, Sabbato pango, Encito lentos, Dissipo ventos, Paco cruentos."

The bells of Dawlish Church were rung during the storm, in the belief that the spirit of the bells would overcome the spirit of the lightning.—1901.

The bells at the village of Palan Perpignan were being rung by some children to avert a storm when the belfry was struck and four of the children were killed.—1901.

Bees are said to foretell a storm by leaving their hives and flying about the entrances.

Beehive revealed by lightning which struck tree.—Grove Mill, Hitchin, 1900.

Bicycle struck near Taunton. The rider was pushing it by the saddle when the lightning struck the handle bars and twisted the framework out of shape.—1902.

"Crosses are often erected in Piedmont on hay and corn ricks to protect them from fire and lightning. Sometimes they are placed over stables to ward off robbers. In fact the sacred symbol is really regarded by the country folk in much the same light as the insurance company's plate which is affixed to buildings on the Continent, with the advantage too of being free from any premium."—Eustace R. Ball.

St. Elmo's Fire.—"In modern times, around the Mediterranean, these electrical displays have been hailed as the light of St. Clair, St. Nicolas, St. Helena; elsewhere they have had the appellation St. Barbe and St. Elmo. The Portuguese call them Corpo Santo, and the English, Comazants or Corposants. Even at the present day of enlightenment, sailors attach a certain importance to these signs; for they suppose that the apparition of one of these natural lights portends that the severest part of the storm has yet to come, while two of them at once indicate a cessation of the tempest. In all of this we trace an inheritance from antiquity; Pliny, in fact, telling us that these lights are dangerous

and unlucky when coming alone, but that when two come together they bring comfort and foretell a prosperous voyage and chase away that 'dreadful, cursed, and threatening meteor, Hellena.' Thereupon, men at sea invocated the gods Castor and Pollux."*

The captain of the British ship *Mohican* reported that on approaching the American coast, the iron ship entered what is described as a magnetic cloud, and became charged with electricity. "Lambent flames played here and there, the compass was deranged, and the crew felt the sensation of being electrified."†

NOTE.—St. Elmo's Fire is usually in the form of a brush or star of light on the top of a mast or anything pointed. It is not unknown here, and has been seen at Ben Nevis observatory eleven times in four years.

Another variety has often been noticed by Alpine climbers. The late Professor J. D. Forbes, while walking on a glacier, heard a rustling noise come from his alpenstock. He raised his hands, whereupon his fingers fizzed; he inferred, therefore, that they were so near a thundercloud as to be electrified by induction. The phenomena are observed to cease, as a rule, after each peal of thunder, but they are quickly renewed, and at each discharge shocks more or less strong are felt.

Dr. Werner von Siemens, the noted physicist, while on the top of the pyramid of Cheops at Ghizeh during a storm, perceived that a flow of electricity escaped from his finger when extended towards the heavens. The current manifested itself powerfully enough to cause a hissing noise, and from the metal button of his guard he obtained electric sparks.

"The dry cold of the winter in Manitoba, according to Professor Bullet, of Winnipeg, is attended by manifestations of electricity. By sliding the feet on the carpet one can electrify the body so that a finger yields a spark and ignites a gas jet. This effect, however, can be produced in many parts of America. One writer says that after electrifying his hand he attracted to it the filament of an incandescent lamp."—*Globe*, May 5th, 1905.

GLOBULAR LIGHTNING.

This, although imitated in the laboratory by Planté and others, still puzzles us a good deal. There are many authenticated instances of the phenomenon. Count G. Hamilton records that at his house on the shores of Lake Wener, twenty seconds after a very vivid flash, a brilliant white ball was seen over the dining table, which disappeared almost immediately with an explosion.

"At Nieheim, in Westphalia, six people saw a ball of fire descend in a house which was burnt to the ground."—*Engineering*, June, 1902.

* "Pre-scientific Electricity."—Hayden.

† *Standard*, August, 1904.

Mr. Perry F. Nursey, C.E., gave an interesting account in the *Morning Post*, August 5th, 1904, of globular lightning which fell in the Buckingham Palace Road, and more recently Mr. C. S. Northcote, M.I.E.E., writing to the *Electrical Review*, May, 1905, states "that he distinctly saw a ball of fire descend during the recent storm, at about the time St. Mathias Church, Richmond, was struck."

"An account from Milan, 1841, states that a globe of lightning moved so slowly over a street that spectators followed in its rear, watching its final dissolution on contact with a church spire.

"On February 4th, 1863, when Nelson's monument on Calton Hill, Edinburgh, was struck, the lightning appeared under the influence of powerful air currents, being driven forward with a rapid motion. Another report from Paris states that a globe of lightning was visible descending from the sky, and equal in size to the full moon. On bursting, vivid zig-zag flashes were visible, and a hole the size of a cannon-ball was rent in a neighbouring house. Globular lightning, as reported to have been seen in the Glendowan Mountains, in county Donegal, was remarkable. A ball of fire was visible for twenty minutes. When first seen, its estimated size was 2 feet in diameter, and of a bright red hue; on disappearing, it had shrunk to 3 inches in diameter. After numerous contacts with the soil in its passage, it entered a river bank, cutting a large trench through the peat to a considerable depth, ejecting the *débris* into the centre of the stream, and buried itself in the opposite bank."

Another account, as seen by Dr. Tripe, on July 11th, 1874, and contributed by him to the Meteorological Society, states, "that he saw, when looking due South during a very heavy thunderstorm, a large ball of fire rise up till it reached a height of about 45 degrees. when it started off towards the West with such remarkable rapidity as to produce the appearance of a flash of forked lightning, finally entering a dark cloud and disappearing."

Curious effects.—"At yesterday's meeting of the Royal Meteorological Society the Rev. C. F. Box gave an account of some curious 'Effects of a Lightning Stroke at Earl's Fee, Bowers Gifford, Essex, April 13th, 1904.' A thunderstorm occurred during the early morning hours, and about 3 A.M. there was a blinding flash, lighting up the whole neighbourhood for miles around, followed immediately by a crashing explosion. One person stated that he saw what appeared to be a cylinder, and another person a ball of fire, descend and then explode, 'casting darts' in all directions. On

careful examination in daylight, it was found that in an oatfield, which had recently been dredged, there were three distinct sets of holes, ranging from 9 inches down to about 1 inch in diameter. The holes, which were circular, diminished in size as they went downwards, and remained so on to the perfected rounded ends at the bottom. Upon digging sectionally into the soil, which is stiff yellow clay, it was found that the holes were 'as clean cut as though bored with an augur.'"

Invoking lightning.—Methodist Minister, Strondesbury, Pennsylvania, said to have prayed that lightning might strike a brewery nearing completion. The brewery was struck and destroyed; owner sued the pastor for damages.—1900.

Hats off to the lightning.—"You must take your hat off to the lightning in the South American town of Quito, unless you want to be guilty of very bad form," states *Cassell's Saturday Journal.* "There the lightning is deeply respected. Everyone removes his hat when it flashes, no matter if rain is falling; and when the streets are busy and lightning is abundant, a grotesque effect is produced by these salutations, which seem to be regarded as a duty by all well-behaved persons."

"A lightning rod was erected by a farmer in Russia, but when the peasants heard that it was used to divert the thunderstorms, they concluded that it had caused a drought from which they were suffering, so proceeded to demolish it."—*Standard*, 1905.

The spectrum of lightning was photographed at Harvard U.S.A., in 1902. The spectrum varies, but many lines appear due to hydrogen, and it is curiously like that of the new star Perseus.

Dark lightning.—"Watching a thunderstorm with brilliant flashes, I was surprised to see with great vividness two nearly vertical lines of darkness on a suddenly illuminated sky, each having the jagged appearance of lightning. I remember to have seen two real flashes of just the same shape and relative positions, and concluded that the black flashes were due to their residual influence on the retina. Turning my eyes quickly to an illuminated wall inside the house I again saw the same double dark flash."—Lord Kelvin, *Nature*, 1901.

Lightning-struck houses not rebuilt.—"Valerius Publicola had his house on the Palatine destroyed, and he built a new one on the site, but the Quirites objected to anyone

building on a spot consecrated by Jupiter's sacred fire, so he had to pull it down."—"Pictures of Old Rome," Frances Elliot.

Lightning conductors, Egyptian.—"Flagstaffs in front of palaces and temples were surmounted with yellow metal spikes made of an alloy, and the pole was partly covered with a thin foil of the same metal. A priest discovered that this would protect the building from the fiery thunderbolt of Typhon."—H. B. Proctor, 1898.

Roman superstition.—"Artaxerxes believed that two swords, planted in the ground, dispersed the thunderclouds. In the time of Charlemagne, poles were used for the same purpose, but, unfortunately for those that would deprive Franklin of scientific renown, they were not supposed to have any efficacy until bits of magical paper had been stuck upon them.

"The ancients also believed that lightning never fell except by the immediate interposition of the gods; and whatever thing or place it struck was ever after deemed sacred—consecrated by the deity himself. The Greeks placed an urn over the spot where the lightning entered the earth, and the Romans had a similar observance. Herodotus tells us that when Scyles, who had studied the language and sciences of Greece, ascended the Scythian throne, it was his desire to be initiated into the mysteries of Bacchus, which was against the wish of his people; and as he was about to take some of the sacred utensils in his hands, his palace in the city of Borysthenites was totally demolished by a thunderbolt.

"To imitate thunder and lightning was considered a sacrilege by all religions. There is an exciting passage in Virgil, wherein the poet describes the infernal regions and the fate of Salmoneus. This prince, according to the legend, wished to be called a god, and to receive divine honors from his subjects. Therefore, to imitate thunder, he used to drive his chariot over a brazen bridge; and to counterfeit lightning, he darted torches on every side. This impiety provoked Jupiter. Salmoneus was struck by a thunderbolt, and placed in the infernal regions near his brother Sisyphus."—"Pre-scientific Electricity," R. Hayden.

"Curiously enough, the ancients do not appear to have represented the actual flash, but have made thunder and lightning an attribute of the gods; thus Jove's thunderbolts are often mentioned and usually depicted by the old masters as darts held in the hand ready to be hurled.

"At the Dorrien Palace, Genoa, instead of these being of the usual form, they are more like rods surrounded throughout their length with lambent tongues of fire. In the time of the Romans lightning was much observed in augury, and was a good or bad omen according to the circumstances attending it. Persons killed by lightning, being thought hateful to the gods, were buried apart by themselves lest the ashes of other men should receive polution from them. It is said that they were generally buried where they fell, probably from the reason now universally accepted that decomposition sets in very quickly in the bodies of those killed by lightning, even preventing in case of sheep or oxen, their carcasses being dressed for market. The Romans had also the good sense to avoid places struck by lightning, which were often fenced in so that no one could use the houses on which Jove had set the mark of his displeasure. To this day the same buildings are struck from time to time, and certain localities are visited by thunderstorms more than others; this knowledge is taken advantage of by the witch-doctors of South Africa, who are said to stand fearlessly on a certain spot during a terrific storm."—"Protection from Lightning," R.I.B.A., K. Hedges, 1900.

Lightning in a clear sky.—This is said to be common in San Domingo.—U.S. Weather Bureau, 1901.

Long lightning conductor.—The top is some distance above the meteorological station on the Zugspitze, Germany. It continues down the side of the mountain to a body of water; the length of the rod is three and a half miles.

Remedy against lightning.—"The Abyssinians have great dread of lightning, and an Italian doctor, having injected ether into a man insensible through a stroke, ether is now considered a 'remedy against lightning.'"—*Pall Mall*, October, 1901.

Measuring a flash.—"A picture was taken from a window of the Hamburg observatory which included a building and the flash that struck the building at the moment of uncovering the lens. It was therefore calculated that this particular flash was 5 mm., or one-fifth of an inch, across."—*Chambers' Journal*, August, 1901.

"Passing between two earth plates buried in ground 60 feet apart, the resistance of the earth should not be more than an equivalent resistance which would allow a current of two ampères at four volts."—Trotter, 1901.

"One hears a great deal of the intensity of a lightning stroke, and various surmises have been made as to the number of volts required to cause a flash to leave the clouds and dart through the atmosphere—a medium which is of such high resistance that with the most powerful electric currents that are in general use, 1 foot of air space is considered perfect insulation. On this subject we have the interesting experiments of Sir William Preece with the Warren de la Rue battery, which were published in the British Association report of 1880, and more recently the experiment of Prof. John Trowbridge (published last year) with 150 plate-glass condensers, 18 inches by 20 inches, $\frac{1}{8}$ inch thick, charged to 20,000 volts by means of 10,000 Planté cells. The professor has since increased the charge to 42,000 volts, and by use of Leyden jars he has obtained a pressure estimated at 2,000,000 volts. He remarks: 'I cannot go higher for the interesting reason that air at atmospheric pressure becomes a fairly good conductor beyond 2,000,000 volts, and it is impossible to charge Leyden jars to this potential or to produce sparks in a laboratory of greater length than 7 feet. To obtain the manifestations of 3,000,000 volts it would be necessary to put the apparatus in an open field, at least 30 feet from the ground, and remote from all other objects. Jars and circuits charged for this high voltage emit a luminous discharge to the floor of the room and to the brick walls, and indicate by this inductive discharge the presence of steam pipes 20 feet distant. The air breaks down quickly under this powerful electrical stress, and behaves like a rarefied gas.'*

"It is well known that lightning shatters stone and pulverises the finest growth of the forest, and this must be due to the quantity of the electric discharge, which has for some extraordinary reason been greatly underestimated. Herr Pockels has devised an ingenious arrangement for measuring the currents that pass through a lightning conductor by testing the residual magnetism in bars of basalt, which were placed cross-wise near a lightning conductor and tested after a lightning discharge had passed. On examination of two bars thus exposed at the observation tower on Mont Cimone in the Appenines, it was inferred that the currents were respectively 10,200 and 5,330 amperes. It was held that the maximum current

* The difference of potential for a spark a mile long between flat plates is roughly 16,000,000 electro-static units, each one of which is equal to 300 volts, that is, nearly 5,000 million volts.—Lodge.

which has passed by or through the lightning rods was quite double these figures, as the bars were not tested till several months after the lightning discharge, and had in the meantime suffered vibration, which would partially demagnetise them."—" Protection from Lightning," British Association, K. Hedges, 1901.

Lightning tree.—The oak has thus been so called in "As You Like It." Celia, speaking of Orlando, says, "I found him under a tree like a dropped acorn." Rosalind rejoins, "It may well be called Jove's tree, when it brings forth such fruit."

"The wood of trees struck by lightning are not burnt by the Kentucky negro, for fear that his house will burn if struck."—*Journal of American Folk Lore.*

Circular action.—A ribbon of bark on a fir tree near Forenville was stripped from the trunk in a spiral line of almost mathematical regularity.—1903.

Rifles struck.—" Eighteen soldiers were sleeping in a bell tent with their eighteen rifles stacked against the centre pole. The flash divided among the rifles and killed all the men."—H. S. Carhart, *American Electrician.*

Liner struck, December, 1903.—The Teutonic was struck in a snowstorm, when 200 miles east of Newfoundland. The masts are of hollow steel, except for the tops, which for a distance of 13 feet are of wood. The lightning splintered the wooden top, and the rope halliards used to hoist flags were rolled up like a ball and driven through the opening.

The thunder flower.—" The stonecrop is known in the lake district by this name, and in old times was planted on farm-houses to protect them from thunderstorms."—*The Garden*, 1901.

Naphtha set on fire. Barge struck, unloading, Thames Haven ; also **Gun-cotton** exploded, Nobel's Works, Ardeer, Ayrshire. —This was probably caused by a side flash from the neighbouring wires, which were struck.—K. Hedges, observer, 1900.

Altar of church at Els, South Austria, set on fire.—1900.

Hot Spring at Amarron saltfields, Indian territory, U.S.A. (about 20 feet by 60 feet), was struck and said to have been set on fire, and continued to burn for some time.—1901. (Probably a petroleum spring.—AUTHOR.)

The Pernod Distillery at Portarlier was struck and destroyed. The flash, conducted by the electric light wires, set fire to the alcohol in the cellars and 600,000 gallons were destroyed.—August, 1901.

Upward motion stroke.—" There is no reason to doubt that the discharge sometimes takes place from earth to cloud. That is to say, that while we now consider a lightning flash as something like the discharge of a condenser through its own dielectric, made up of excessively frequent alternations—say, something like 300,000 times per second—the spark, or core of incandescent air, may seem to have its beginning at the earth's surface, that is to say, the air gap breaks down first at a point near the earth."—McAdie and Henry, Washington, 1899.

Velocity of storms.—W. A. Eady, of U.S.A., observed that the actual thunderstorm had a velocity at the height of three quarters of a mile of more than double that of the velocity one hour in advance of the storm. He also noted a circular draught of air, proving that thunderstorms have a slight rotary motion.—1901.

William Maine's account of the effects of **lightning** on his **rod,** dated at Indian Land, in South Carolina, August 28th, 1760 :—

" I had a set of electrical points consisting of three prongs of large brass wire tipt with silver, and perfectly sharp, each about 7 inches long; these were riveted at equal distances into an iron nut, about three-quarters of an inch square, and opened at top equally to the distance of 6 or 7 inches from point to point, in a regular triangle. This nut was screwed very tight on the top of an iron rod of above half-an-inch diameter, or the thickness of a common curtain rod, composed of several joints, annexed by hooks turned at the end at each joint, and the whole fixed to the chimney of my house by iron staples. The points were elevated 6 or 7 inches above the top of the chimney, and the lower joint sunk 3 feet in the earth, in a perpendicular direction.

" Thus stood the points on Tuesday last about five in the evening, when the lightning broke with a violent explosion on the chimney, cut the rod square off just under the nut, and I am persuaded, melted the points nut, and top of the rod entirely up ; as after the most diligent search nothing of either was found and the top of the remaining rod was cased over with a congealed solder. The lightning ran down the rod, starting almost all the staples and unhooking the joints without affecting the rod, except on the inside of each hook where the joints were coupled, the surface of which was melted and left as cased over with solder. No part of the chimney was damaged only at the foundation where it was torn out. Considerable

cavities were made in the earth quite round and several bricks were torn out. It also shattered the bottom weather-board at one corner of the house, and made a large hole in the earth by the corner post. On the other side of the chimney it ploughed up several furrows in the earth, some yards in length. It ran down the inside of the chimney carrying only soot with it; and filled the whole house with its smoke and dust. It tore up the earth in several places and broke some pieces of china in the beaufet. A copper tea-kettle standing in the chimney was beat together, as if some great weight had fallen upon it, and three holes each about half-an-inch diameter, melted through the bottom. What seems to me most surprising is, that the hearth under the kettle was not hurt, yet the bottom of the kettle was drove inward, as if the lightning proceeded from under it upwards, and the cover was thrown to the middle of the floor. The fire-dogs, an iron loggerhead, an Indian pot, an earthen cup, and a cat were all in the chimney at the time unhurt, though great part of the hearth was torn up. My wife's sister, two children and a negro wench, were all who happened to be in the house at the time. The first, and one child, sat within 5 feet of the chimney, and were so stunned that they never saw the lightning nor heard the explosion: the wench with the other child in her arms, sitting at a greater distance, was sensible of both; though everyone was so stunned that they did not recover for some time; however it pleased God that no further mischief ensued."

[redacted] **Benjamin Franklin on lightning rods,** Letter LIX., Paris, 1767:—

"It is therefore that we elevate the upper end of the rod six or eight feet above the highest part of the building, tapering it gradually to a fine sharp point, which is gilt to prevent rusting. Thus the pointed rod either prevents a stroke from the cloud, or, if a stroke is made, conducts it to the earth with safety to the building."

*WEIGHTS OF COPPER STRANDED CABLE

(Consisting of seven wires twisted together).

Weights per foot, about:	$\frac{3}{8}$-in.	$\frac{1}{2}$-in.	$\frac{5}{8}$-in.	$\frac{3}{4}$-in.	$\frac{7}{8}$-in. diameter.
	6 ozs.	10 ozs.	$15\frac{1}{2}$ ozs.	$22\frac{1}{2}$ ozs.	$30\frac{3}{4}$ ozs.

COPPER, TAPE OR FLAT BAND.

Weights per foot, about:	$\frac{3}{4} \times \frac{1}{8}$ in.	$1 \times \frac{1}{8}$ in.	$1\frac{1}{4} \times \frac{1}{8}$ in.	$1\frac{1}{2} \times \frac{1}{8}$ in.	$2 \times \frac{1}{8}$ in.
	6 ozs.	8 ozs.	10 ozs.	12 ozs.	15·46 ozs.
	$\frac{3}{4} \times \frac{3}{16}$ in.	$1 \times \frac{3}{16}$ in.	$1\frac{1}{4} \times \frac{3}{16}$ in.	$1\frac{1}{2} \times \frac{3}{16}$ in.	$2 \times \frac{3}{16}$ in.
	9 ozs.	12 ozs.	15 ozs.	18 ozs.	23·19 ozs.

* Furnished by Frederick Smith & Co., Salford.

SOLID ROD.

Weights per foot, about:	$\frac{1}{4}$-in.	$\frac{5}{16}$-in.	$\frac{3}{8}$-in. diameter.
	3 ozs.	$4\frac{3}{4}$ ozs.	7 ozs.

Copper weighs ·321 lbs. per cubic inch, or 555 lbs. per cubic foot, and has a specific gravity of 8·912 at 60° Fah. Tensile strength of hand-drawn wire is 22 to 28 tons per square inch section.

IRON WIRE STRANDED CABLE

(Consisting of seven strands).

Weights per fathom of 6 feet, about:	$\frac{3}{8}$-in.	$\frac{1}{2}$-in.	$\frac{5}{8}$-in.	$\frac{3}{4}$-in. diameter.
	1·7 lbs.	2·25 lbs.	4·5 lbs.	6·2 lbs.

1d. per lb.	=	**£9**	**6**	**8**	**per ton.**
$\frac{1}{2}$d.	,, =		**4**	**13**	**4**	,,
$\frac{1}{4}$d.	,, =		**2**	**6**	**8**	,,

TABLE OF CONDUCTORS IN ORDER OF CONDUCTIVITY.

Silver.	**Copper.**	**Gold.**	**Aluminium.**
Zinc.	**Iron.**	**Lead.**	**Charcoal.**

Those substances which allow electricity to flow through them are called **Conductors,** and those which do not are called **Insulators.**

Ampere Meter.—An instrument used for measuring strength of current.

Earth.—A conductor is said to be "earthed" when it is so arranged that it makes good electrical connection with the ground.

Ohm.—The unit of resistance.

Resistance.—The opposition presented by the circuit to the flow of current in it.

HISTORICAL SUMMARY.

1717. Reiman, a Pole, saw lightning run along iron rods without injuring them, but shattering stone between.

1751. Franklin's kite experiments.

1752. De Lor de Buffon erects an iron pole 99 feet high mounted on a cake of resin.

,, Franklin—He makes known the action of lightning rods.

1753. ,, He erects the first conductor.

,, Richmann killed at St. Petersburg by a stroke from his insulated vertical rod.

1767. Franklin's conductors erected at St. Paul's Cathedral. *

1771. The controversy of knobs instead of points for conductors and the matter referred to George III.* Franklin was then fighting against the crown.

1820. Application of Lightning Conductors to ships by Snow Harris.

1876. Clerk Maxwell on the Protection of Buildings from Lightning. Paper read before the British Association.

1878. Conference of learned societies.

1881. The Lightning Rod Conference Report published.

1884. Paper read at the Royal Institute of British Architects by Col. the Hon. A. Parnell on the action of lightning strokes.

1888. Oliver Lodge delivered the Dr. Mann Lectures at the Society of Arts.

,, Joint discussion of Sections A and G at the Bath meeting of the British Association.

* There is some uncertainty as to the exact date, a portion of the original iron conductor, can be seen at the Victoria & Albert Museum.—AUTHOR.

1889. Paper read by Oliver Lodge on Lightning, Lightning Conductors and Protectors. Institute Electrical Engineers.

1899. U. S. Department of Agriculture. Weather Bureau. Lightning and Electricity in the Air.

1900. Paper read by Killingworth Hedges on the Protection of Buildings from Lightning, at the Royal Institute of British Architects, describing his re-arrangement of Lightning Conductors at St. Paul's Cathedral.

1901. The Lightning Research Committee initiated by Killingworth Hedges. A paper read at the Glasgow meeting of the British Association.

1902. A system of Conductors designed for Westminster Abbey.

1904. The action of Lightning strokes on Buildings. Hedges. British Association Meeting, Cambridge.

1905. April 10th. The Lightning Research Committee's Report published.

1910. Phœnix Assurance Company's Rules drafted by Sir Oliver Lodge, Killingworth Hedges, and Castle Russell.

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* *POINTS OR KNOBS.*

"While you, great George, for knowledge hunt,
And sharp conductors change for blunt,
The nation's out of joint;
Franklin a wiser course pursues,
And all your thunder useless views
By keeping to the point."

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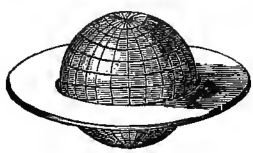

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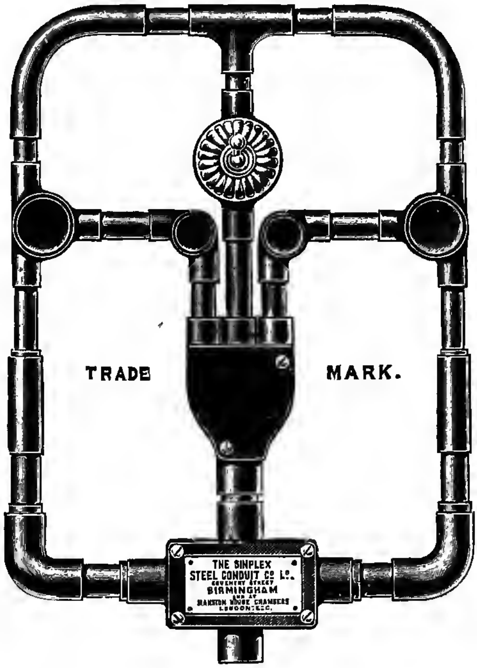

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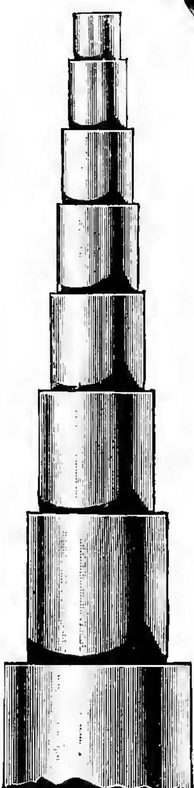

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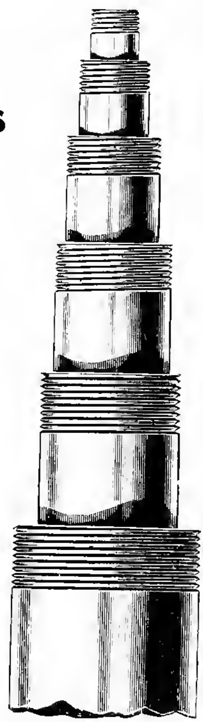

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